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The influence of shelf life on food waste: A model-based approach by empirical market evidence

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ABSTRACT

Several million tons of food are wasted annually and solutions to completely face the problem are not still available. It is well recognized that shelf life prolongation could play a key role for reducing food waste but the real relation between shelf life and food waste is not well assessed for lack of actual market data. Therefore, the aim of this work was to identify the relationship between the shelf life and an important food waste component, i.e. the product returned from the market, by using a proper statistical approach, adapted to data kindly offered by a domestic industry. The mathematical model highlighted an inverse function between shelf life and product returned only when the shelf life is between 30 and 50 days. This means that for specific products with shelf life in this range (30–50 days), a proper prolongation could significantly reduce the amount of products returned from the market, if unsold within their commercial life.

1. Introduction

About a third of food amount globally produced for human consumption is lost or wasted, around 1.3 billion tons per year, according to the Food and Agriculture Organization (FAO, 2011). Food waste is a significant contributor to the overall EU negative environmental impacts, responsible for 17% of direct greenhouse gas emissions and 28% of material resource use. In the EU it is estimated that nearly 100 million tons of food are wasted annually. For the future it is expected an increase of food waste due to consumer preference for perishable products, as well as for foods that require reduced time for preparation and cooking (Lundqvist et al., 2008); therefore, the challenge will be more oriented to balance convenience, packaging, shelf life and food waste for each type of product (Verghese et al., 2013). If nothing is done, food waste could rise to over 120 million tons by 2020. The target set at the European level aims at 50% prevention of avoidable food waste by 2025 (European Parliament, 2012). Wasting food is not only an ethical and economic issue but it also depletes the environment of limited natural resources (Stancu et al., 2016).

Numerous efforts to classify and quantify food discards and to define reasons and responsibilities of discard generation have been reported (Farr-Wharton et al., 2014; Girotto et al., 2015). Food discard occurs at all stages of food life cycle, starting from harvesting, through processing, production and distribution, until domestic handling and final consumption (Lipinski et al., 2013; Schneider, 2008).

To face the problem, various efforts have been made (Gjerres and Gaiani, 2013; Grunert et al., 2014; van Donselaar et al., 2006; Taylor and Fearne, 2009; WRAP, 2013), even though the complexity of food supply chains, as well as consumption behaviors lead to consider that a multidisciplinary approach could be strictly necessary. Manzocco et al. (2016) in a review work dealing with technological and consumer strategies to tackle food wasting, stated that it is necessary to consider that very often companies limit their investments in more modern preservation technologies aimed to reduce food discard after sale and prefer focusing on strategies to reduce the food loss before sale. The authors, giving an overview of possible interventions for waste reduction/prevention at industrial and domestic levels, suggest that food technology, marketing and legislation should be merged with a special attention to food loss and food waste to implement strategies able to provide a new concept of food quality. The so-called "waste hierarchy" orders possible management options according to their sustainability, intended as environmental impact, as well as social and economic benefits (Papargyropoulou et al., 2014). It also

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introduces the prevention concept, intended as reduction of discard generation. Waste hierarchy was developed to raise general awareness and encourage people to think beyond traditional management options (Ohlsson, 2004; Tucker and Douglas, 2007), but although it represents a tool to identify the best management options, no quantitative data about its efficacy are still available.

As a key to the food waste problem, one of the most attractive solutions is to allow products to last longer through a wide range of preservation techniques (Zhang et al., 2015). In this context the potential role of thermal and non-thermal processes or new packaging solutions to extend the shelf life of fresh foods, as a way to prevent food spoilage and strengthen sustainability of food system *have been explored* (Conte et al., 2015; Williams and Wikström, 2011; Wikström and Williams, 2010; Williams et al., 2012). However, there is lack of evidence whether a longer shelf life necessarily reduces waste in terms of guarantee consumption before reaching the best before date. As a fact, Amani and Gadde (2015) on a comprehensive literature review and empirical findings from several studies of food supply chains, highlighted that personnel working at production warehouses, as well as retail stores, are more inclined to control the storage levels of products with shorter shelf life and prioritize their handling in comparison with long-life products. This is due to the evidence that the longer the shelf life, the longer the time in storage. These conditions may be part of the explanation why in general it is not possible to state that the increase in the shelf life completely remove the waste at the storage because the flow of goods was slowed down from production to distribution. The authors concluded that would be beneficial to develop a method to investigate and monitor the effectiveness of proposed shelf life extension solutions for the purpose of food waste reduction.

Being of interest the identification of the determinants of food waste and the real relation with food shelf life, the current paper focuses on a possible quantified relationship between food shelf life and waste. To this aim, thanks to the availability of real market data kindly offered by a domestic industry, a statistical analysis was allowed to identify a possible mathematical function correlating products shelf life with an important food waste component, *i.e.* the product returned from the market.

2. Materials and methods

2.1. Samples

Data utilized in the current study were provided by a large Italian food company. Data of a total 828 [826?] food products pertaining to different categories (typology and size) were taken into account. Specifically, 640 typologies of dairy products were considered: market milk (fresh pasteurized, ESL/extended shelf-life, UHT; regular, organic, lactose-free, flavored), cream (fresh pasteurized, ESL, UHT), yoghurt and fermented milk, dairy dessert, butter (regular/low fat, lactose-free), toddler and baby food products (plain and flavored milk, GUM, yogurt and dessert), ripened and unripened cheese from cow's, water buffalo's, goat's and ewe's milk (soft, firm, hard and extra-hard), ricotta (from cow's, goat's and ewe's whey), goat's milk (ESL and UHT) and yogurt. In addition a variety of non-dairy products, including beverages and ready meals, were considered, for further 186 products.

2.2. Statistical analysis

The variables considered for each product were (i) shelf life and (ii) product returned from the market, expressed as *Returned Goods Ratio* (RGR) = returned goods (tons)/delivered goods (tons). Shelf life means the length of time between the moment when the product is manufactured and packed and the one when it becomes unacceptable. Returned goods mean the products returned from the market, mainly due to expired shelf life date. The shelf life is discretized into 17 ranges, in order to consider together different types of products, which share a common range of shelf life (Table 1).

Firstly, a descriptive analysis was carried out to evaluate the mean and standard deviation (SD) of RGR value for each identified shelf life range. Then, the one-way ANOVA was used for testing the significant differences in RGR values with respect to the 17 ranges of shelf life. Further, multiple/post hoc group comparisons were carried out. Finally, a model-based approach was proposed to analyze the relationship between shelf life and RGR. In particular, the coefficients of inverse model were estimated by least square regression. The inverse equation form is:

$$y = b_0 + b_1/x$$

where, ‘y’ is the dependent variable, b_0 represents the equation intercept and b_1 is the regression coefficient. The statistical validation of the inverse equation was established by analysis of variance approach to regression analysis (ANOVA for regression).

All statistical analyses were conducted with the IBM SPSS 20, Statistical Package for the Social Sciences Program.

3. Results and discussion

3.1. Descriptive analysis

In Table 2, data of descriptive analysis are reported. As can be seen, the main feature of the experimental data is that in the first 30 days of shelf life the RGR values tend to fluctuate without a specific trend. In particular, between 11 and 20 days the highest values of RGR were found and from 16 to 20 days a high variability of RGR was measured (SD = 0.160). Contrary, from 31 days for all the investigated shelf life ranges the mean value of RGR seems to decline with a specific trend. As regard data form distribution, the last column of Table 2 highlights that skewness values always show a positive asymmetry. In order to highlight eventual statistical significant differences in RGR values according to the shelf life ranges, the ANOVA test was carried out. Results are reported in Table 3 ($F = 10.27$, $p < 0.001$) where a confirmation of significant differences among RGR values can be found. For a deep investigation, multiple/post hoc group comparisons were also carried out

Table 1
Frequency and Frequency Percent of goods for range shelf life.

Shelf life range (days)	Frequency of goods	Frequency Percent of goods
1–10	68	6.9
11–15	14	1.4
16–20	28	2.9
21–25	76	7.7
26–30	86	8.8
31–40	139	14.2
41–50	83	8.5
51–60	44	4.5
61–70	30	3.1
71–80	22	2.2
81–100	108	11.0
101–130	99	10.1
131–150	32	3.3
151–200	68	6.9
201–300	30	3.1
301–700	46	4.7
>700	8	0.8
Total	981	100.0

Table 2
Descriptive statistics of *Returned Goods Ratio* (RGR) for shelf life's range.

Shelf life range (days)	Mean(95%CI)	Standard deviation	Maximum	Skewness
1–10	0.061(0.045–0.077)	0.067	0.416	2.576
11–15	0.080(0.028–0.132)	0.090	0.301	1.323
16–20	0.084(0.022–0.146)	0.160	0.739	3.415
21–25	0.037(0.028–0.045)	0.037	0.161	1.376
26–30	0.041(0.026–0.057)	0.072	0.500	4.016
31–40	0.071(0.056–0.087)	0.092	0.486	2.084
41–50	0.064(0.043–0.084)	0.093	0.531	3.032
51–60	0.041(0.018–0.065)	0.077	0.438	3.650
61–70	0.025(0.015–0.035)	0.027	0.105	1.212
71–80	0.015(0.000–0.030)	0.033	0.152	3.686
81–100	0.018(0.007–0.028)	0.056	0.409	4.646
101–130	0.006(0.004–0.009)	0.015	0.082	3.335
131–150	0.006(0.001–0.011)	0.013	0.056	2.776
151–200	0.004(0.001–0.007)	0.014	0.104	5.828
201–300	0.001(0.000–0.001)	0.001	0.005	2.029
301–700	0.000(0.000–0.000)	0.001	0.004	5.655
>700	0.000(0.000–0.000)	0.000	0.000	0.000

Table 3
One-Way Analysis of Variance of RGR by Shelf life range considering all shelf life ranges.

Source	Sum of squares	df	Mean square	F	p value
Between groups	71.4,333,567	16	.044	10.27	0.000
Within groups	418.937.097	964	.004		
Total	490.370.453	980	.005		

with RGR value referred to the first 30 days of shelf life (Table 4). Results show that differences are not statistically significant if RGR values are compared each other in the short term (shelf life ranges from 1 to 30 days).

3.2. Model-based approach to define the relation between shelf life and food waste

On the basis of the statistical findings reported in the previous paragraph, an inverse model was adopted to highlight the relationship between RGR and shelf life, when ranges higher than 30 days are taken into account. The summary of the inverse model and the related estimated parameters ($R^2 = 0.453$) are reported in Table 5. The equation is reported in the follow:

$$RGR = -0.009 + 3.866/\text{Shelf life}$$

In Fig. 1 plot of observed data and fit model are represented. As can be shown in the figure, the RGR values are very high until about 50 days of shelf life and then greatly fall down for longer shelf life ranges. In order to determine whether there is a significant relationship between the RGR and shelf life, expressed by the inverse model, an ANOVA regression was performed (Table 6). P-value is statistically highly significant ($p < 0.001$), then the relationship between the two data sets is well represented by the above-mentioned inverse model.

Considering the good RGR findings recorded for long shelf life data and also taking into account that their behavior can be also due to the commercial restrictions on goods return generally applied by food manufacturers and accepted by retailers, the firms attention should be mainly focused on food products with middle shelf life values (30 days < shelf life < 50 days). The empirical model shows that large amounts of product with middle shelf life are discarded from the market if unsold within their commercial life. Faced with a growing world population, this is totally unacceptable, thus

Table 4
Multiple comparison of *Returned Goods Ratio* (RGR) by shelf life ranges ≤30.

Shelf life range		Mean Difference	SD error	p value	95% Confidence Interval	
					Lower Bound	Upper Bound
1–10	11–15	−0.00098	0.02907	1.000	−0.0883	0.0863
	16–20	−0.01736	0.04118	1.000	−0.1392	0.1045
	21–25	0.04050	0.01864	0.284	−0.0132	0.0942
	26–30	0.03569	0.01986	0.544	−0.0212	0.0926
11–15	1–10	0.00098	0.02907	1.000	−0.0863	0.0883
	16–20	0.01637	0.04339	1.000	−0.1450	0.1123
	21–25	0.04149	0.02311	0.629	−0.0352	0.1181
	26–30	0.03667	0.02411	0.797	−0.0411	0.1145
16–20	1–10	0.01736	0.04118	1.000	−0.1045	0.1392
	11–150	0.01637	0.04339	1.000	−0.1123	0.1450
	21–25	0.05786	0.03722	0.756	−0.0553	0.1710
	26–30	0.05304	0.03785	0.848	−0.0614	0.1675
21–25	1–10	−0.04050	0.01864	0.284	−0.0942	0.0132
	11–150	−0.04149	0.02311	0.629	−0.1181	0.0352
	16–20	−0.05786	0.03722	0.756	−0.1710	0.0553
	26–30	−0.00482	0.00916	1.000	−0.0309	0.0213
26–30	1–10	−0.03569	0.01986	0.544	−0.0926	0.0212
	11–15	−0.03667	0.02411	0.797	−0.1145	0.0411
	16–20	−0.05304	0.03785	0.848	−0.1675	0.0614
	21–25	0.00482	0.00916	1.000	−0.0213	0.0309

Table 5
Coefficient of inverse model.

	Unstandardized Coefficients		Standardized Coefficients	t	p value
	B	STD Error	Beta		
1/x	3.866	0.689	.673	5.612	0.000
Constant	−0.009	0.012		−0.738	0.465

Dependent Variable: Returned Goods Ratio; independent variable shelf life.

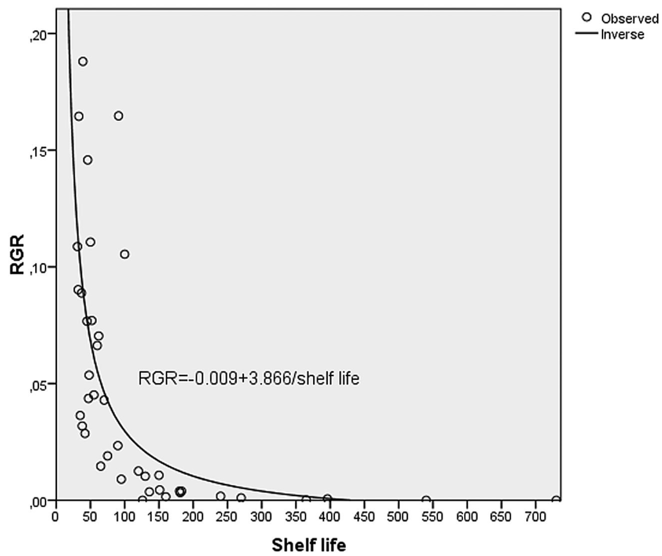

Fig. 1. Plot of observed data and fit model (shelf life >30 days).

Table 6
Anova regression for inverse model.

	Sum of Squares	df	Mean Square	F	Sig.
Regression	0.050	1	0.050	31.496	0.000
Residual	0.060	38	0.002		
Total	0.110	39			

Dependent Variable: Returned Goods Ratio; independent variable shelf life.

suggesting that the major trend in food supply chains should be to rely on proper shelf life extension solutions. The findings of the model-based approach in fact suggest that proper shelf life prolongation for specific types of fresh products (*i.e. yogurt)* could really contribute to prevent food waste and in particular RGR value. Data from the warehouse of Swedish dairy producer also showed a considerable reduction in waste when shelf life for cream and yoghurt was extended three times (Amani and Gadde, 2015). One of the most recognized tools for shelf life extension can be represented by optimized packaging solutions. The best packaging system should improve the balance between the environmental impact of the package itself and the impact deriving from the potential loss of the packaged product, which in turn is strictly related to its shelf life (Marsh and Bugusu, 2007; Williams and Wikström, 2011). In the same context, Zhang et al. (2015) provided a link between food loss saving and the food packaging system's overall environmental performance. Conte et al. (2015) provided an eco-indicator able to quantify the environmental indirect effects related to the different choices in the packaging of a ripened cheese obtained from sheep milk. The authors highlighted that if indirect effects of food loss probability are also taken into account (e.g. production and transport of cheese in order to reconstruct the stockpile), the multilayer systems under modified headspace conditions are more sustainable than thinner and recyclable packaging materials sealed in air, due to the high environmental impacts of the cheese production compared to production and disposing of packaging materials.

Anyhow, the situation is more complicated and consequently the solutions to the food waste problem must be critically examined to determine whether they can fulfill their promises of reducing food waste, considering the whole chain in the entire life cycle of the product (Mena et al., 2011; Parfitt et al., 2010; Watson and Meah, 2013). As a fact, it is also worth considering that other important factors than shelf life can come into play, thus causing an increase in RGR. Among them, industrial man actions, marketing strategies, logistics, customer, plan and sales can be cited (European Parliament, 2012). As regard human factor, over-production caused by non-compliance of the production plan or by incorrect programming, causes surplus of supply on the market and consequently high levels of RGR. In addition, lack of quality industrial control system can provoke increase of RGR, due to defects to food products caused by industrial operators. In sense of marketing strategies, the excess of product assortment, incorrect product design or unsuitable introductory product offer can also allow to increase RGR. In the logistics category, extended stock over terms of efficiency or inefficient transport can also generate RGR (Jedermann et al., 2014). As far as the customer marketing concerns, temperature and all other important environmental conditions should guarantee RGR control. In terms of plan factor, an under-estimation of the promotions made in view of the shelf life expiration cannot favorite RGR decrease. Finally, in terms of sales, over load of retailer storehouse can be still determinant for a high RGR.

4. Conclusions

In this work a statistical analysis carried out on Italian market data highlighted an inverse correlation between quantity of products returned from the market and their shelf life. The model approach showed a significant regressive model by inverse curve, explaining the relation between the two variables only for products whose shelf life exceeds 30 days. Results suggest that strategic efforts in terms of shelf life prolongation could face the food waste, in particular for products that reach the "best before date" between 30 and 50 days. Anyhow, the complex patterns of the supply chain imply to manage food waste with the aim of defining better protocols and procedures and identify interdisciplinary approach to consider not only product safety and quality, but also environmental and social impact.

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