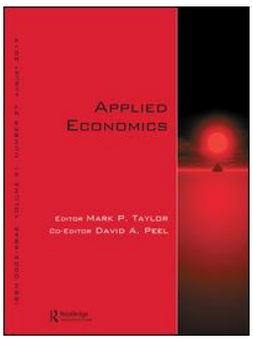

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Food waste as a consequence of an inefficient consumer's choices: a microeconomic approach

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ABSTRACT

This study frames the household food waste challenge in the microeconomic theory context by proposing a model that considers food waste a consequence of inefficient consumer choices. A data envelopment analysis (DEA) methodology was applied to factor consumer's efficiency level dimension, starting from data collected through a web survey conducted in Italy with a sample of 530 individuals responsible for their households' food-shopping. The findings confirm that food waste is a complex issue, affected by both behavioural and psychological factors, synthesized in three indices constructed with fuzzy analysis. The results show that the shopping behaviour index generates a higher average efficiency score for food waste minimization than the food waste concerns and moral attitudes indices. Furthermore, those drivers have different efficiency levels in reducing food waste with reference to gender, age, family composition, and educational level. The results have several implications for policymakers: they highlight the need to implement tailored educational and information campaigns that consider the most important targets identified, such as large families with children, young people, and men.

KEYWORDS

Fuzzy analysis; food waste minimization; data envelopment analysis; efficient consumer

JEL CLASSIFICATION

C14; C67; C80; D12.

I. Introduction

The reduction of food waste (FW) has been recognized as an urgent issue due to the public concerns about the expected world population growth, increased pressure on environmental resources, and changes in dietary patterns. In recent years, this phenomenon has assumed increasing importance in scientific debates and international political agendas. The United Nations 2030 Agenda for Sustainable Development includes the topic of FW in several goals: zero hunger, clean water and sanitation, and promoting responsible consumption and production.

FW has been associated with certain ecological, economic, and social externalities. From a social perspective, FW poses a significant challenge to global food security. According to the Food and Agricultural Organization (FAO), reducing the food wasted globally by 25% could feed 821 million chronically undernourished persons worldwide (FAO 2013). Furthermore, the COVID-19 crisis has highlighted important changes related to food access and security, requiring that further attention be paid to the issue of FW (Cattaneo et al. 2020).

In terms of the environmental impacts, the FAO (2019) estimates that FW accounts for 8% of global greenhouse gas emissions and uses approximately 30% of the world's agricultural land. At the same time, the global footprint of 'blue' water for agricultural production linked to FW is approximately 250 km^3. The FAO (2014) estimated the economic value of food wasted globally at approximately 1 trillion dollars/year, which refers to not only the actual production costs of wasted food but also the so-called 'hidden' costs. According to FAO (2014), these hidden costs are attributable to conflicts over the control of natural resources, treatment of diseases related to pesticide use in agriculture, natural habitats loss and related ecosystem services, the effects of climate change and reduced water availability, and the public subsidies for food production. In summary, it is evident that FW is a source of environmental, economic, and

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social degradation, and for these reasons, it is important to study how it can be curbed.

The identification of the causes of FW and the implementation of measures to minimize it represent an opportunity to reduce, more generally, the impacts of the agri-food system on a social and environmental level, but, above all, to redefine the global production and consumption patterns.

The existing literature concludes that, even if FW occurs in all stages of the food supply chain, in developed countries, large amounts of food are wasted at the end of the food supply chain, and private households represent key actors in this (Canali et al. 2017; Schanes, Dobernig, and Gözet 2018). In European countries, for example, the EU Fusions Project (2016) has estimated that over 50% of FW occurs at the household level.

Furthermore, it is widely recognized that FW at the household level is a complex behaviour affected by multiple drivers, including socio-economic, psychological, situational, and demographic factors (Principato et al. 2021; Quested et al. 2013).

Households' consumption patterns have significantly changed in the last decades, especially in industrialized countries. According to Gjerris and Gaiani (2013) food is abundant, cheap, and available everywhere and at any time for most citizens. In this regard, the scholars argue that people find it extremely difficult to realize how much food they throw away and, consequently how they could act against FW, because discarding food is often an irrational action whose effects are an increase in the economic costs[1] incurred by consumers and in the negative externalities generated by their behaviour. This seems to be in contrast with the economic theory of the rational consumer whose goal is to minimize the economic and environmental costs associated with FW.

Despite the extensive literature on household FW, most existing studies attempted to explain the wasteful behaviour by reiterating the Theory of Planned Behaviour (Ajzen 1991), which is among the most-used framework to analyse and predict consumer behaviour. However, the different levels of efficiency of behavioural and psychological drives in reducing FW at the household level has not been specifically addressed. Overall, as pointed out by Drabik, de Gorter, and Reynolds (2019), micro-foundational economic models for FW at the consumer level are yet to be developed to better understand the true economic drivers of food waste and the economic shifts caused by food waste reduction. Although the consumer choice process has been extensively studied in the economic literature, not much has been said about the role of efficient consumption choices (see Blakrishnan, Nataraajan, and Desai 2000).

Based on the above, the current study aims to extend the existing knowledge on household FW by applying a microeconomic model according to which FW can be considered a consequence of inefficient consumer choices. The consumer's efficient choice theory is derived from the axiom of rationality in the consumer's decision-making process. In particular, this axiom states that consumers are rational in choosing the quantity of goods (food in our case) to be consumed in the most efficient manner from an economic perspective – that is, the quantity of goods that maximizes utility, satisfies the budget constraint, and does not generate waste. This is because according to classical economic theory, a rational agent aims to minimize FW and efficiently use his/her share of income destined for food consumption.

In particular, the objectives of the present study are (i) to present an economic model of FW minimization considering both psychological and behavioural drivers, which, through the income destined for food consumption, affect the FW level; (ii) to construct appropriate indices to be used in the consumer efficiency analysis; and (iii) to analyse the profile of consumers who operate efficiently by minimizing FW, using survey data from consumers in Italy as a case study.

The remainder of this study is organized as follows: Section 2 describes the theoretical framework. Section 3 presents the questionnaire design, data collection, and methods. Section 4 presents the results, whereas Section 5 discusses the results and indicates some policy implications.

[1]The Waste Watcher Observatory estimated that on average, in Italy, the weekly household FW account for 4.9 € of the family budget, and a total of approximately € 6.5 billion only during 2020.

II. Theoretical framework

Microeconomic model of FW minimization

In this section, we present a microeconomic model in which a rational agent aims to minimize FW and efficiently use the share of his/her income destined for food consumption. In particular, the rational agent must solve a minimization problem of a quadratic loss function, $\mathcal{L}$, subject to the budget constraint:

$$Min\mathcal{L} = \frac{1}{n}\sum_i \left(F_i - F_i^*\right)^2$$

s.t. (1)

$$\sum_i p_i F_i = R(\alpha)$$

F_i is the consumed amount of the *i-th* food, and F_i^* is the target amount or minimum subsistence objective for the *i-th* food. For each food *i*, $\left(F_i - F_i^*\right)^2$ represents the deviation of the consumed amount of the *i-th* food from its target. When $F_i = F_i^*$, the typical consumer is not wasting any of the *i-th* food.

The budget constraint indicates that the value of food (the sum of the p_iF_i) must be equal to the income intended for food consumption, $R(\alpha)$. The latter depends negatively on behavioural or psychological factors of deterrence to FW (α): $\frac{\delta R}{\delta \alpha} < 0$.

The quadratic $\mathcal{L}$ function allows us to consider equally both positive and negative deviations of individual food consumption from their targets. In particular, when the difference in parentheses in equation (1) is positive, this constitutes FW; in contrast, when the difference in parentheses is negative, it represents a situation of food thrift in terms of food choices (for fashion or diet reasons, etc.) or to economic unavailability preventing the target from being reached (poverty).

We can solve this constrained minimization problem by transforming it into an unconstrained minimization problem through Lagrange's method. We will write the Lagrange function as follows:

$$\Lambda = \frac{1}{n}\sum_i \left(F_i - F_i^*\right)^2 + \lambda\left(R(\alpha) - \sum_i p_i F_i\right) \quad (2)$$

From the first-order conditions, we have

$$\frac{\delta\Lambda}{\delta F_i} = 0, \lambda = \frac{\sum_i \left(F_i - F_i^*\right)}{\sum_i p_i}$$
$$\frac{\delta\Lambda}{\delta\lambda} = 0, \sum_i p_i F_i = R(\alpha)$$

After appropriate substitutions, we obtain $F_i = \frac{F_i^* * \sum_{j\neq i} p_j^2}{\sum_i p_i^2} - \frac{p_i * \sum_{j\neq i} F_j^* * p_j}{\sum_i p_i^2} + \frac{p_i R(\alpha)}{\sum_i p_i^2}$ (3)

From this, it follows that $\frac{\delta F_i}{\delta F_i^*} > 0$, $\frac{\delta F_i}{\delta F_j^*} < 0$, and $\frac{\delta F_i}{\delta R(\alpha)} > 0$.

In the case that the amount of the *i-th* food coincides with its target, we have $F_i = F_i^*$ and

$$F_i^* = \frac{R(\alpha) - \sum_{j\neq i} F_j^* p_j}{p_i} \quad (4)$$

In this case, we observe that the demand for the *i-th* food positively depends on the income intended for the purchase of food and negatively depends on the other foods' targets ($j \neq i$).

Economic efficiency of consumer choices and FW minimization

In this study, in line with Blakrishnan, Nataraajan, and Desai (2000), we adopt the view of Fornell, Robinson, and Wernerfelt (1985), who compare the consumption of products by consumers to a production process. From this perspective, a product purchased by the consumer is to be considered as an input of the production process, converted into output through the consumption process. The output of this production process is the utility or satisfaction that stems from having consumed the product purchased. The utility maximization problem is a disutility minimization problem created by purchasing excess amounts of goods that will never be consumed and that generate waste and income loss. In this case, the behavioural and psychological factors that could generate a reduction in FW (and allow a reduction in the income intended for consumption) will represent the inputs of our production process, while FW will represent our output (bad output).

A rational consumer will always want to ensure that he/she makes the best possible choices, equivalent to the lowest FW level. After all, consumption rationality implies the notion of economic

efficiency. In other words, among all the possible FW levels, the one that provides the lowest loss will be chosen (Hauser and Gaskin 1984). To select the most economically efficient waste level, the rational consumer must be aware of the different choices, which are conditioned by the impacts of the behavioural and psychological factors that guide the choice process, and, therefore, by the amount of effort required to adapt the FW amount to one's individual needs. As stated earlier, this basic assumption of consumer rationality, in the sense of choosing the most economically efficient FW level, is undoubtedly part of consumption patterns. In this study, we empirically investigate the validity of this cardinal assumption (Blakrishnan, Nataraajan, and Desai 2000).

Relevant literature on the factors affecting FW at the consumer level

The literature on domestic FW and the factors that generate it is extensive (for a recent systematic review, see Principato et al. 2021). Most existing studies that have been conducted at a national level have shown that the FW amount differs significantly among countries and those differences may be partially attributable to the difference in consumption habits (Hanssen, Syversen, and Stø 2016). A common key finding of the major recent research, summarized in Table 1, is the centrality of both behavioural and psychological factors in influencing wasteful behaviour.

Considering the former, food shopping practices and routines are decisive in limiting FW generation at the consumer level. In their research in Italy and Germany, Jörissen, Priefer, and Bräutigam (2015) estimated that using a shopping list can reduce the FW amount per capita by 20%. Likewise, Stancu, Haugaard, and Lähteenmäki (2016) and Secondi, Principato, and Laureti (2015) showed that for EU consumers, making shopping lists or checking the existing provisions before shopping positively influences FW reduction. In their study on young adults in Italy and Spain, Mondéjar-Jiménez et al. (2016) argued that planning routines develop positive behaviours towards FW, whereas failure to check food provisions and avoiding the preparation of a shopping list increase the food wastage probability. A similar result was highlighted by Janssens et al. (2019), showing that for Dutch consumers, the lack of food preparation planning is one of the most significant barriers to reducing FW, leading to consumers buying more food than needed.

Considering in-store behaviour, an interesting study by Bravi et al. (2020) in different European countries found that negative in-store behaviours are related to an increase in FW because of consumers' exposure to marketing promotions that encourage overprovisioning or bulk purchases. However, the extent of this influence differs among countries and is more relevant for consumers in the UK than those living in Italy and Spain (Bravi et al. 2020). Overall, food overprovisioning is strongly connected to individuals' attraction to special offers and in-store marketing strategies (Janssens et al. 2019; Jörissen, Priefer, and Bräutigam 2015; Mondéjar-Jiménez et al. 2016). Further, Graham-Rowe, Jessop, and Sparks (2014) suggest that the time constraints during shopping and meal preparation may generate more FW for UK households.

Other studies found that in-home eating behaviour and preferences and storage practices also affect FW generation. Ponis et al. (2017) found that, for Greek consumers, eating preferences have a direct effect on FW generation. Sarić et al. (2020) showed that for Croatian consumers, noting quantities while cooking and eating domestic food are important factors in avoiding FW. While Bilska and colleagues (2020) showed that the most common causes for FW among Polish consumers include food being expired, missing the expiry date, and failure in storage practices. Falasconi et al. (2019) showed that in Italy, purchasing and cooking too much food were both related to a higher FW declared, suggesting that better food purchasing planning could have a role in decreasing FW at home.

Regarding psychological factors, numerous studies have highlighted that moral attitudes and concerns play an important role in influencing the intention not to waste food. Russell et al. (2017), for example, showed that in the UK, consumers who experienced more negative emotion when thinking about FW intended to reduce their wasteful behaviour further. In the same way, for

Table 1. Recent research on household FW: key findings.

Author/s and year	Geographical coverage	Main findings
Bilska, Tomaszewska, and Kołożyn-Krajewska (2020)	Poland	Food becoming spoilt, missing the expiry date, and failure in storage practices are the most common causes of FW. Young people and those with university-level education are more likely to buy unplanned products and waste food.
Bravi et al. (2020)	UK, Spain, and Italy	In-store behaviour and food management at home are relevant in reducing the frequency of FW in all three countries.
Cantaragiu (2019)	Romania	Attitudes towards FW evolve as individuals age, and at each stage, women tend to be more concerned about the negative impact of food waste on social equity or the family budget than men.
Falasconi et al. (2019)	Italy	Food habits, purchasing, and cooking too much are key determinants of the extent of FW declared. Better food purchase planning could have a role in decreasing household FW.
Graham-Rowe, Jessop, and Sparks (2014)	UK	Time pressure during shopping and time constraints for the meal preparation are barriers to minimizing FW. Waste concerns and the desire of doing the 'right' thing are core motives to reduce FW.
Hanssen, Syversen, and Stø 2016	Norway	Households of different sizes or with different age structures show no significant differences in the amount of edible food waste/per person. Households in the urban region generated more edible FW than in most rural regions.
Janssens et al. (2019)	Netherlands	Purchase behaviour in-store is the main driver of FW (i.e. buying more food than needed). Intention not to waste food acts as a moderator in the relationship between planning behaviour and FW.
Jörissen, Priefer, and Bräutigam (2015)	Italy and Germany	Households' shopping practices have a huge impact on the level of FW. Individuals that are attracted by special offers waste more food because they are encouraged by retailers to buy more than needed.
Mondéjar-Jiménez et al. (2016)	Italy and Spain	Moral attitudes and concern towards FW influence the intention to reduce FW. Marketing and sales strategies promoted by food companies have a direct and negative effect on consumer behaviour.
Neff, Spiker, and Truant (2015)	USA	Saving money and setting an example for children are the leading motivations for waste reduction while environmental concerns ranked last. Concern about food-borne illnesses and a desire to eat only the freshest food are the most common reasons for FW.
Ponis et al. (2017)	Greece	Shopping habits and eating preferences are important FW determinants, however, causes of avoidable FW mediate the effect of shopping habits.
Principato, Secondi, and Pratesi (2015)	Italy	Greater awareness about the consequences of FW increases the likelihood of adopting a planned food-shopping routine.
Qi and Roe (2016)	USA	Consumers who express greater awareness for FW are more likely to feel guilty when throwing away food.
Russell et al. (2017)	UK	Negative emotions are associated with greater intention to reduce FW but are also associated with higher levels of FW behaviour. A greater sense of control strongly influences the intentions to engage in anti-waste behaviour.
Sarić et al. (2020)	Croatia	Being careful of quantities during cooking and eating domestic food are important factors to avoid FW. The desire to save money is more closely related to the intention to avoid FW than protecting the environment. Higher education and taking notice of quantities during cooking and eating result in less wasteful behaviour.
Secondi, Principato, and Laureti (2015)	EU −27	Both individual and contextual variables are associated with FW generation at the household level. Income, education, and context of residence are relevant variables in explaining differences in households' FW generation.
Stancu, Haugaard, and Lähteenmäki (2016)	Denmark	Food-related routines (i.e. planning, shopping, and leftovers reuse) are the main drivers of FW, besides perceived behavioural control.
Stefan et al. (2013)	Romania	Moral attitudes and perceived behavioural control affect shopping routines and subsequent FW generation.

Romanian and UK consumers, Stefan et al. (2013) and Quested et al. (2013), respectively, showed that consumers feel guilty about or are bothered by their wasteful behaviour, and those feelings strongly affect their intentions to reduce FW. Further, Qi and Roe (2016) and Neff, Spiker, and Truant (2015) found that most households in the USA feel guilty about FW generation and these feelings of guilt act more strongly in determining their intention to reduce waste than environmental concerns about the negative FW effects.

Additionally, FW concerns play an important role in shaping individuals' intention to reduce FW. Graham-Rowe, Jessop, and Sparks (2014) found that waste concerns, together with the desire to do the 'right' thing, are core motives to reduce FW for UK consumers. Principato, Secondi, and Pratesi (2015) and Mondéjar-Jiménez et al. (2016) found that young individuals more concerned about the environmental and social impacts of FW are more likely to change their behaviour. Conversely, Neff, Spiker, and Truant (2015), Stancu, Haugaard, and Lähteenmäki (2016), and Sarić et al. (2020) found that personal concerns (i.e. saving money and time) exert greater influence on wasteful behaviour. Particularly, Sarić et al.

(2020) found that, Croatian consumers' avoiding FW is mainly motivated by the need to save money rather than the desire to protect the environment. This evidence may also be connected to the influence of the country's economic situation. Indeed, Secondi, Principato, and Laureti (2015), compared the EU 27 and showed that those households with a lower income or from lower-income countries waste less.

Furthermore, the authors indicate that individuals with a lower educational attainment and not in the labour force waste less food (Secondi, Principato, and Laureti 2015). This is also confirmed by other studies in European countries (e.g. Bilska, Tomaszewska, and Kołożyn-Krajewska 2020) who found that people with higher-level education are more likely to waste food because of the time constraints on food management at home. Conversely, Sarić et al. (2020) found that highly educated consumers tend to avoid FW more than the less educated ones.

The household composition also affects the FW generation. In their literature review, Principato et al. (2021) report that larger households tend to waste more than smaller ones and that the presence of children increases the probability of wasting more food. However, Hanssen, Syversen, and Stø (2016) found that smaller households, especially those with only one person, generate the most FW per capita.

Regarding age, several studies found that younger consumers tend to waste more than older ones because of their habit of buying unplanned products (Bilska, Tomaszewska, and Kołożyn-Krajewska 2020; Principato et al. 2021; Stancu, Haugaard, and Lähteenmäki 2016). However, it is interesting to consider that, as suggested by Bilska, Tomaszewska, and Kołożyn-Krajewska (2020), the difference between younger and older consumers in FW generation may vary also among different product groups. Further, the literature varied in its findings on the influence of gender on FW. Indeed, some studies found that gender had no significant influence (Janssens et al. 2019) while others showed that men are more prone to waste. An interesting study in Romania from Cantaragiu (2019) found that the effect of gender on FW was different depending on age group, reflecting the fact that women's roles changes with age, as they become responsible for cooking for the entire household.

III. Materials and methods

We apply a data envelopment analysis (DEA) to assess consumers' efficiency in reducing FW and a fuzzy analysis to construct the indices used as inputs and output. To test the proposed model, data on FW (output) and behavioural and psychological factors affecting FW (inputs) were collected via a web-based survey conducted in Italy.

Questionnaire design and data collection

To test the proposed model, data were collected using a web-based survey conducted in Italy during January 2020 by a national market research company[2] (Astra Ricerche). The survey targeted consumers aged between 18 and 75 years who were responsible for their household food-shopping. A quota sampling method was applied based on the place of residence (considering the four Nielsen areas of North-west, North-east, Central, and South of Italy). The final sample consisted of 530 respondents.

The questionnaire used comprised five sections and contained food-shopping routine measures and habits, awareness of and motivation for FW, self-reported FW behaviour, moral norms and concerns about FW, and socio-demographics (see Tables 2 and 3 for the measures included in the economic models).

Food-shopping routines and habits were assessed using 11 items selected from previous research (Bravi et al. 2020; Mondéjar-Jiménez et al. 2016; Stancu, Haugaard, and Lähteenmäki

[2]The data that support this study's findings are available from the corresponding author upon reasonable request.
The national market research company (Astra Ricerche) collected participants informed written consent.

2016) asking respondents to indicate how much the given items reflected their shopping behaviour.

Awareness about and motivations behind FW were assessed by asking respondents to indicate their level of knowledge about FW and the degree of importance of nine motivations in determining their wasteful behaviour, selected from previous research (Falasconi et al. 2019).

Self-reported FW behaviour was measured by asking respondents to indicate the frequency of wasting foods weekly (ranging from 1 = never to 6 = daily), overall, and concerning specific food types. The food types were selected based on a reduced version of the list provided by MIPAFF-Crea Observatory.[3]

Moral attitudes, related to feeling guilty or sorry for wasting food, were measured using six items adapted from Stefan et al. (2013) and Stancu, Haugaard, and Lähteenmäki (2016), while concerns about FW consequences were assessed with six items related to environmental, social, and economic impacts (Mondéjar-Jiménez et al. 2016; Principato, Secondi, and Pratesi 2015). For all the items, a five-point Likert scale ranging from 1 = 'not at all' to 5 = 'very much' was used.

Questionnaire understandability and length were pre-tested with a pilot sample of 20 consumers before proceeding with the main survey.

DEA

The method used in this study to assess consumers' efficiency in reducing their FW level was a DEA, a non-parametric method used to assess the relative technical efficiency of a set of similar operating units (also called decision-making units [DMUs]). It uses a deterministic linear programme to estimate a frontier technology (Charnes, Cooper, and Rhodes 1978; Ganley and Cubbin 1992). DMUs located on the frontier are fully efficient; they are performing better than any units below the frontier.

The model used in this study to obtain a measure of technical relative efficiency is the output-oriented one, under the assumption of variable returns to scale. This DEA model, known as BCC (Banker, Charnes, and Cooper 1984), assumes that changing the inputs will not result in a proportional change in the outputs. We formally present the model we apply as follows: Consider a set of n DMUs ($j = 1, \ldots, n$), each consuming varying amount of m different inputs to produce s different outputs. The relative efficiency of a DMU j_0 is obtained as follows (Banker, Charnes, and Cooper 1984):

$$h_0 = max\sigma_0$$

subject to

$$\sum_{j=1}^{n} \lambda_j x_{ij} \leq x_{ij0}, i = 1, \ldots, m$$

$$\sigma_0 y_{rj0} - \sum_{j=1}^{n} \lambda_j y_{rj} \leq 0, r = 1, \ldots, s$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

where y_{rj} is the amount of the r-th output by DMU j, x_{ij} is the amount of the i-th input to DMU j, and λ_j are the DMU j weights.

This linear programming problem must be solved n times for each unit, to obtain the value of σ, representing the technical output efficiency of DMU j_0. This value is bounded between 0 and 1: $\sigma = 1$ indicates that the unit is one of those that define the frontier, and, therefore, it is fully efficient, while values less than the unity indicate that the unit is relatively inefficient.

The identification of the input and output variables to be used in an assessment of comparative performance is the first and the most important stage in conducting the evaluation (Thanassoulis 2001). However, the non-parametric approach to efficiency measurement does not offer any tools that can aid researchers in specifying the most appropriate model. To address this drawback, much attention must be paid to the selection of the input-output set, focusing on what is postulated by the efficiency theory and what is indicated in the particular context under investigation.

In our analysis, it is important to highlight that the output, FW, is 'bad output' and it makes no

[3]https://www.crea.gov.it/documents/59764/0/Osservatorio+CREA+O-ERSA+WEB.pdf/c93f0266-e5f7-e2f3-e581-32797328bb3b?t=1559138880594

sense to maximize it; on the contrary, it must be minimized. There are several possibilities for dealing with undesirable factors in DEA models; to avoid excessive data manipulation, we simply invert the scale of the questionnaire questions, transforming them from negative to positive.[4] Thus, we obtain an index, hereinafter referred to as the wise food consumption index (WFCI).

Finally, as inputs, we consider three indices related to behavioural and psychological factors affecting FW: the shopping behaviour index (SBI), FW concern index (FWCI), and moral attitudes towards FW index (MAI).

Fuzzy analysis

To construct the four indices (WFCI, SBI, FWCI, and MAI), fuzzy set theory has been used.

Fuzzy set theory, conceptualized by Zadeh (1965) and developed by Dubois and Prade (1980), is a mathematical tool for analysing phenomena that may be roughly placed in a set. Sets are, in turn, defined as 'a class of objects with a continuum of grades of membership' (Zadeh 1965). While the early applications of fuzzy sets theory were in science and engineering, it has later been applied to many issues in the social sciences (see Annunziata, Agovino, and Mariani 2019; Cerioli and Zani 1990; Cheli and Lemmi 1995; Chiappero Martinetti 2000).

Fuzzy set theory prescribes a four-step procedure: 1) variables selection, 2) membership functions construction (MFs), 3) calculation of the weights associated with each MF, and 4) MFs aggregation.

The variables used to construct the indices are those indicated by the questionnaire and are shown in Table 3. For each of these variables, we proceed with the construction of the relative MF (see Zani, Milioli, and Morlini 2013). MFs based on the totally fuzzy and relative approaches suggested by Cheli and Lemmi (1995) allow transforming a discrete variable into a continuous one.

Particularly, let X be a set of elements $x \in X$. A fuzzy subset A of X is the set of ordered pairs

$$\left[x, \mu_A(x)\right] \quad x \in X \tag{7}$$

where $\mu_A(x)$is the MF associating x with A through the interval [0, 1]. If $\mu_A(x) = 0$, then x does not belong to A, while if $\mu_A(x) = 1$, x completely belongs to A. If $0 < \mu_A(x) < 1$, x partially belongs to A, and its membership in A increases with the value of $\mu_A(x)$. In our case, $\mu_A(x) = 1$ identifies a situation of full achievement of the target (e.g. in the case of WFCI, consumers have an attitude of full responsibility towards the purchase of food, with a high probability of eliminating FW). $\mu_A(x) = 0$ denotes a total failure (consumers have an attitude of total irresponsibility towards the purchase of food) and $0 < \mu_A(x) < 1$ refers to a situation between these two extremes. The notion of frequency is instrumental to the definition of the MF. Particularly, considering a set of n units (indexed by $i = 1, 2, \ldots, n$) and assuming a non-linear and monotonic relation between the p manifest variables X_s(where $s = 1, 2, \ldots, p$) and the degrees of membership, the modalities of the variables may be ordered to obtain the following MF:

$$\mu_A(x_i) = \begin{cases} 0, if x_i \leq l \\ \mu_A(x_{i-1}) + \frac{F(x_i) - F(x_{i-1})}{1 - F\left(x_{i(l)}\right)}, if l < x_i < u \\ 1, if x_i \geq u, \end{cases} \tag{8}$$

where $F(x_{si})$ is the cumulative sampling function of variable X and $x_{i(l)}$ is the highest value such that . If $l = x_l = min(x_i)$ and $u = x_n = max(x_i)$, the MF of equation (8) corresponds to the totally fuzzy and relative approach suggested by Cheli and Lemmi (1995).

To build a composite index, the weights associated with each MF must be defined. The literature suggests a weighting procedure that considers, for each variable X_s, the fuzzy proportion of target achievement, with

[4]The first possibility would simply be to ignore the undesirable factors but since we only have one output, we cannot eliminate it from the analysis. The second would be to treat the undesirable outputs as inputs and the undesirable inputs as outputs; this possibility was also excluded because we only have one output. However, this does not reflect the true production process. The third would be to treat the undesirable outputs in a non-linear DEA model (see Färe et al. 1989). The fourth would be to apply a monotone decreasing transformation (e.g. $1/y_{ri}$) to the undesirable outputs and to use the transformed variables as outputs.

$$g(X_s) = \frac{1}{n}\sum_{i=1}^{n}\mu(x_{si}). \quad (9)$$

Normalized weights can be the inverse of$g(X_s)$, to assign higher importance to rarer features in the n units. To avoid attributing excessive weights to the variables with low values of, we follow Cerioli and Zani (1990):

$$w_s = \frac{log\left(\frac{1}{g(X_s)}\right)}{\sum_{s=1}^{p} log\left(\frac{1}{g(X_s)}\right)} \quad (10)$$

The weights are thus determined statistically and objectively, remaining unaffected by subjective considerations. Finally, MFs are aggregated through weighted arithmetic mean.

IV. Results

Sample description

The main socio-demographic characteristics of the sample are summarized in Table 2: 51% of the respondents were females, and 22% were aged 45–54 years, whereas each of the 35–44 years and 55–65 years age groups accounted for 19% of the respondents. Further, 56% of the respondents had a high school diploma and 15% of them a master's degree; 42% were employed, 14% were retired, and 14% were housewives. Regarding family size, 33% of the respondents lived in households comprising two members while 30% were in households of three members; only 23% had a child under the

Table 2. Socio-demographic and economic variables.

		%
Gender	Male	49.4
	Female	50.6
Age	18–24	9.4
	25–34	14.7
	35–44	18.6
	45–54	22.1
	55–64	18.8
	65–75	16.4
Education	Lower than a high school diploma	12.5
	High school diploma	56.8
	Bachelor's degree	10.0
	Master's degree	15.1
	PhD/Postgraduate specialization	5.7
Residence area	North-west	26.2
	North-east	18.9
	Centre	22.6
	South	32.3
Employment	Employee	42.1
	Housewife	14.2
	Retired	14.3
Family size	Single	9.1
	2	33.4
	3	29.8
	4	18.1
	More than 4	9.6
Children < 12 in household	Yes	23.2
	No	76.8
	< 20,000	29.6
Annual family income	Between 20,000–30,000	46.7
	> 30,000	23.7

Table 3. Descriptive statistics of variables and indices (based on 530 obs.).

	Mean	Std. Dev.	Min	Max
SBI	**0.60**	**0.150**	**0.153**	**1**
I like shopping for food	4.02	0.989	1	5
I usually plan food purchases by making a shopping list	3.81	1.133	1	5
I usually check the existing provisions before shopping	4.03	0.993	1	5
I usually decide what to buy only when I am at the supermarket	3.32	1.216	1	5
I usually purchase food that I did not include in the shopping list	2.32	1.031	1	5
I usually buy larger amounts of food when supermarkets offer good value for money	3.83	1.033	1	5
I usually buy food products close to their expiry dates in special offers	3.00	1.185	1	5
I like to try new foods that I have never tasted	3.65	1.080	1	5
For me, the freshness of food products is very important	4.40	0.798	1	5
I always pay attention to the quality/price ratio	4.21	0.868	1	5
I always compare the appearance of different products before buying them	4.36	0.822	1	5
FWCI	**0.65**	**0.282**	**0**	**1**
Waste of environmental resources (water, energy, soil, etc.)	4.24	0.930	1	5
CO2 emissions increase due to the production and transport of food	3.99	1.020	1	5
Waste of economic resources for the purchase of food that is not consumed	4.09	0.981	1	5
Inequalities in food distribution among the world's population	4.11	1.008	1	5
Loss of biodiversity and desertification linked to intensive food production	4.03	0.990	1	5
Waste of economic resources linked to policies for the disposal of food surpluses	4.14	0.948	1	5
MAI	**0.648**	**0.284**	**0.037**	**1**
Wasting foods makes me feel sorry or guilty	4.60	0.751	1	5
I feel guilty about people who do not have enough food	4.29	1.028	1	5
I feel guilty for wasting environmental resources	4.08	1.092	1	5
I feel guilt for contributing to environmental pollution	3.93	1.125	1	5
I feel sorry for wasting money	4.36	0.871	1	5
I feel sorry for wasting time buying and preparing food	3.95	1.107	1	5
WFCI	**0.757**	**0.277**	**0**	**1**
How often are the following categories of food discarded in your household each week?				
Milk	1.80	1.278	1	6
Dairy products	1.89	1.265	1	6
Bread	2.09	1.398	1	6
Bakery products	1.66	1.180	1	6
Fruits and vegetables	2.25	1.295	1	6
Meat/fish	1.72	1.241	1	6
Cold cuts	1.75	1.232	1	6
Rice/pasta	1.68	1.248	1	6
Sauces	1.73	1.202	1	6

age of 12. Almost half of the respondents in the sample self-reported an annual family income between 20,000 and 30,000 euros.

Based on the self-reported behaviour, food wastage occurred primarily less than once a week (31%), or only on special occasions, such as during holidays (25%). Only 4% of the respondents in the sample stated that they wasted food daily. Of all the respondents, 51.5% estimated that they wasted less than 10% of total food bought per week, while 12.5% wasted less than 20%. Among the different categories of food wasted, fruit and vegetables were discarded at least once a week in 23.6% of cases and only on special occasions in 21% of cases; bread was wasted once a week in 17% of cases and more than once a week in 10% of cases. Dairy products, such as yoghurt and milk, were wasted mainly less than once a week (14% and 16%, respectively). Meat and fish were wasted less often. The concern that food was no longer edible because it was not properly stored was on average the main reason for wastage (mean value 3.63), followed by the concern of food poisoning (3.37) or because the food had expired (3.25).

Table 3 reports the descriptive statistics of the variables used in the index construction, and mean values and standard deviations of the indices.

Concerning food-shopping routines and habits, Table 3 shows that on average, the interviewees attach high importance to food products' freshness during shopping (average score: 4.40); they are particularly attentive in comparing products before buying them (4.36) and very sensitive to the quality/price ratio (4.21). Furthermore, the habits of (1) checking existing provisions before shopping and (2) planning food purchases are quite widespread among respondents (mean scores of 4.03 and 3.81, respectively).

The descriptive statistics also show that respondents are very concerned about the environmental and social consequences of their shopping, mainly natural resources waste (average score: 4.24), economic resources waste linked to disposal policies (4.14), and the food distribution inequalities among the world's population (4.11).

Regarding their moral attitudes towards FW, the respondents feel, on average, very sorry or guilty about their wasteful behaviour (4.60) and especially sorry for having wasted their money (4.36) but also guilty about people who do not have enough food (4.29). However, their guilt about wasting environmental resources is slightly lower (4.08).

Given the indices' descriptive statistics values, it emerges from Table 3 that the output of our analysis (WFCI) has a high average value (0.76), showing consumers' tendency to move towards increasingly wiser consumption. Regarding the three inputs, we show that their values vary in the range 0.60–0.65, with SBI assuming the lowest average value and FWCI assuming the highest one. Therefore, consumers exhibit greater sensitivity towards FW. The weights used for each index are reported in the Appendix.

Table 4. Analysis plan.

	Output: WFCI						
Input	Model I	Model II	Model III	Model IV	Model V	Model VI	Model VII
MAI							
SBI							
FWCI							

DEA results

Seven DEA models were used in the analysis. Table 4 shows the combination of inputs used in each model. Specifically, models I, II, and III evaluate the impact of the inputs MAI, SBI, and FWCI, respectively; models IV, V, and V evaluate all two-input combinations. Finally, model VII considers all three inputs at the same time.

Before commenting on the results of the different models considered concerning the socio-demographic and economic characteristics of the consumer sample, we show the efficiency score distributions in the seven models to highlight the input or input combinations that determine the greatest impact regarding reducing FW. Comparing the three models with only one input, Figure 1 shows that the highest average efficiency score is returned by model II (input: SBI) and this is represented by the fact that its efficiency score distribution lies the farthest from the origin. Models I (input: MAI) and III (input: FWCI) show a similar efficiency level (they are mostly overlapping) and greater variability in consumer behaviour (more flattened efficiency score distributions). However, these two distributions have a more pronounced right tail compared to that of

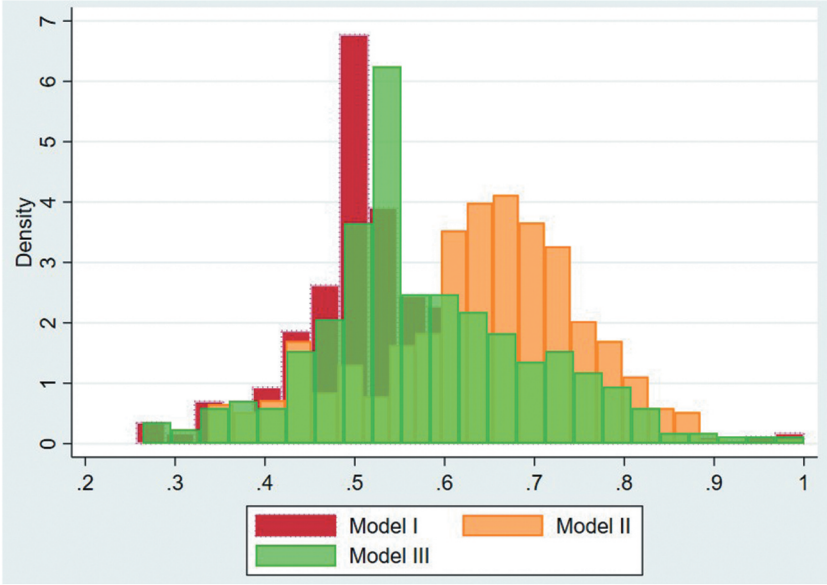

Figure 1. Distribution of the efficiency scores of models I, II, and III.

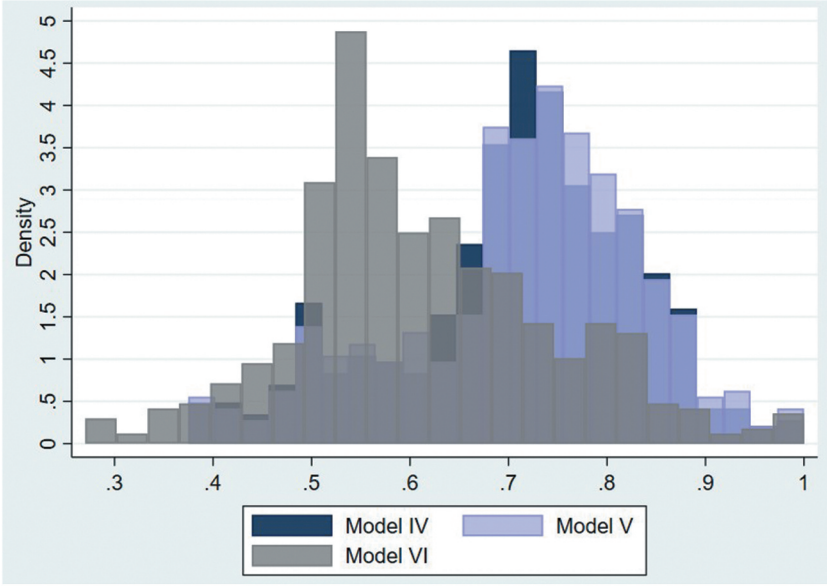

Figure 2. Distribution of the efficiency scores of models IV, V, and VI.

model II and, therefore, exhibit a larger number of consumers who reach a maximum efficiency score (i.e. equal to 1).

Comparing the two-input models (Figure 2), we observe that the most efficient models on average are those that include SBI as one of the two inputs (models IV and V). Furthermore, the combination of the SBI and FWCI inputs (model V) presents a larger number of consumers on the right tail of the distribution where the highest efficiency scores lie. It is, therefore, the combination of SBI and FWCI inputs that pushes consumers to act more efficiently from an economic viewpoint, in the sense of minimizing FW and efficiently using their share of income destined for food consumption.

Finally, Figure 3 shows the distribution of the efficiency scores for model VII, including all the three inputs, plotted against the distributions shown in Figure 3. Model VII shows efficiency scores distribution with a marked positive asymmetry. Unlike the other models, the right tail,

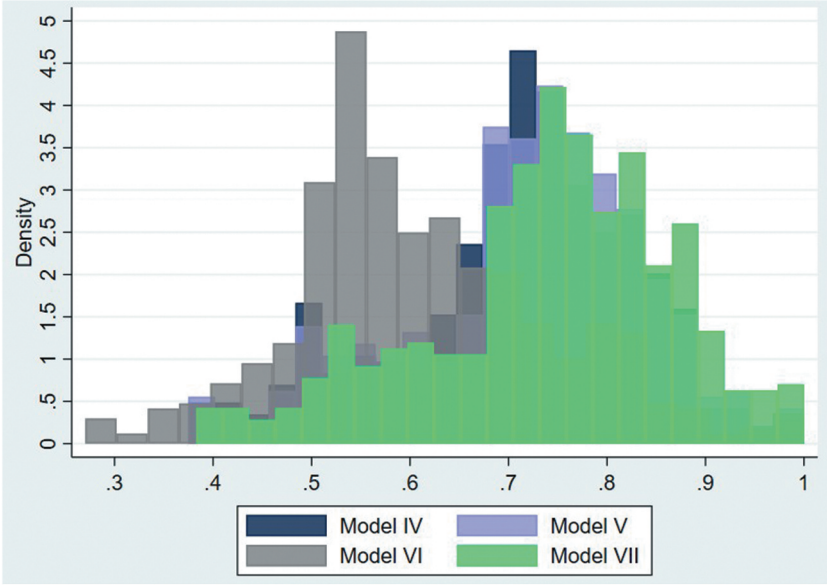

Figure 3. Distribution of the efficiency scores of models IV, V, VI, and VII.

where consumers with the highest efficiency scores are concentrated, comprises a very high percentage of consumers. This leads to the conclusion that the three inputs if considered at the same time, 'result in' more efficient consumer choices. In summary, based on all the graphical results heretofore, we can conclude that the SBI input determines displacements of the distribution farther to the right of the origin (guaranteeing a higher average efficiency), while the MAI and FWCI inputs shift more probability mass to the right tail of the distribution (ensuring that a larger consumer number reach the maximum efficiency score).

Table 5 shows the efficiency scores of models I, II, and III by socio-demographic and economic characteristics and the efficiency gain or loss when comparing different model pairs. Overall, it is confirmed that model II, with only the SBI input, has the highest average efficiency scores.

Regarding gender, the MAI (model I) and FWCI (model III) inputs make males' food consumption choices more efficient than those of females. Regarding efficiency gain and loss, compared with the MAI input, the SBI input creates an efficiency gain of approximately 16% for women and approximately 9% for men. The percentage of earnings for women remains almost unchanged when comparing the SBI and FWCI inputs, while for men it falls to 6%. It is interesting to note that for the SBI input the maximum efficiency score is reached for families with two members, while it is significantly reduced for large families (more than five members with an efficiency score of 0.57). The SBI input produces a greater effect on the efficient choices of consumers who have children under the age of 12; particularly, the efficiency gain concerning the MAI input is approximately 16%. Similar results are also found concerning the FWCI input. When comparing age groups, older people (ages 55–64 and 65–75) exhibit higher efficiency scores; contrastingly, the youngest age group (ages 18–24) has the lowest values. Furthermore, for the SBI input, the maximum efficiency gain (approximately 16%) occurs in the 65–75 age group.

From a geographical perspective, it emerges that when the SBI input is used, consumers in Northern Italy (east and west) achieve the highest efficiency scores. Concerning efficiency gains, it is consumers in the South who record the greatest efficiency gains, when comparing the scores of model II with those of models I and III.

Regarding the income variable, consumers with the lowest income (<20,000 euros) achieve the highest efficiency scores in all the models. Compared with the other inputs, the SBI input (model II) has a greater impact concerning the

Table 5. Efficiency scores of models I, II, and III by socio-demographic and economic characteristics and gain or loss of efficiency when comparing each pair of these models.

Variable	Model I	Model II	Model III	$\Delta_{I\text{-}II}$	$\Delta_{I\text{-}III}$	$\Delta_{II\text{-}III}$
Gender						
Male	0.572	0.630	0.594	−9.23%	−3.70%	6.10%
Female	0.545	0.646	0.559	−15.66%	−2.48%	15.63%
Children aged under 12						
Yes	0.545	0.646	0.559	−15.66%	−2.48%	15.63%
No	0.563	0.649	0.582	−13.30%	−3.29%	11.54%
Age						
18–24	0.543	0.590	0.569	−7.99%	−4.54%	3.74%
25–34	0.559	0.607	0.566	−7.96%	−1.22%	7.32%
35–44	0.553	0.630	0.573	−12.16%	−3.53%	9.82%
45–54	0.547	0.630	0.570	−13.29%	−4.11%	10.58%
55–64	0.576	0.674	0.594	−14.55%	−3.03%	13.48%
65–75	0.569	0.674	0.582	−15.57%	−2.20%	15.84%
Macro area						
North-west	0.565	0.649	0.579	−12.87%	−2.45%	11.97%
North-east	0.581	0.650	0.600	−10.64%	−3.14%	8.39%
Centre	0.562	0.630	0.587	−10.78%	−4.26%	7.30%
South	0.537	0.629	0.553	−14.59%	−2.76%	13.85%
Family Size						
1	0.546	0.653	0.581	−16.46%	−6.04%	12.48%
2	0.567	0.663	0.585	−14.39%	−3.02%	13.28%
3	0.562	0.637	0.578	−11.77%	−2.88%	10.08%
4	0.571	0.623	0.589	−8.34%	−3.07%	5.76%
5+	0.505	0.573	0.511	−11.83%	−1.02%	12.26%
Income						
< 20,000 euros	0.572	0.660	0.587	−13.24%	−2.54%	12.33%
20,000–30.000 euros	0.549	0.621	0.573	−11.53%	−4.12%	8.38%
> 30,000 euros	0.560	0.647	0.570	−13.49%	−1.79%	13.53%
Education						
Lower than a high school diploma	0.556	0.656	0.561	−15.21%	−0.94%	16.83%
High school diploma	0.562	0.637	0.581	−11.71%	−3.12%	9.73%
Bachelor's degree	0.558	0.643	0.585	−13.23%	−4.70%	9.83%
Master's/ specialist degree	0.551	0.634	0.582	−13.10%	−5.23%	9.05%
PhD/ Postgraduate specialization	0.544	0.617	0.537	−11.76%	1.38%	14.89%

Note: $\Delta_{X-Y} = \left(\frac{Eff_X - Eff_Y}{Eff_Y}\right) * 100$ is the gain or loss of efficiency of model X compared with model Y.

Table 6. Efficiency scores of models IV, V, and VI by socio-demographic and economic characteristics and gain or loss of efficiency when comparing each pair of these models.

Variable	model IV	model V	model VI	$\Delta_{IV\text{-}V}$	$\Delta_{IV\text{-}VI}$	$\Delta_{V\text{-}VI}$
Gender						
Male	0.708	0.716	0.631	−1.21%	12.20%	13.57%
Female	0.710	0.715	0.595	−0.65%	19.44%	20.22%
Children aged under 12						
Yes	0.710	0.715	0.595	0.66%	20.22%	19.44%
No	0.719	0.727	0.618	1.10%	17.58%	16.31%
Age						
18–24	0.664	0.672	0.600	−1.19%	10.63%	11.96%
25–34	0.686	0.685	0.608	0.12%	12.84%	12.70%
35–44	0.699	0.707	0.606	−1.11%	15.26%	16.55%
45–54	0.698	0.708	0.605	−1.39%	15.44%	17.06%
55–64	0.745	0.751	0.632	−0.82%	17.91%	18.89%
65–75	0.740	0.747	0.619	−1.00%	19.60%	20.80%
Macro area						
North-west	0.720	0.726	0.619	−0.78%	16.42%	17.33%
North-east	0.726	0.733	0.635	−1.01%	14.38%	15.55%
Centre	0.703	0.712	0.621	−1.35%	13.20%	14.74%
South	0.694	0.699	0.589	−0.71%	17.94%	18.78%
Family Size						
1	0.718	0.736	0.608	−2.45%	17.97%	20.93%
2	0.732	0.741	0.624	−1.26%	17.34%	18.84%
3	0.708	0.712	0.615	−0.64%	15.02%	15.77%
4	0.702	0.704	0.623	−0.24%	12.71%	12.99%
5+	0.637	0.639	0.549	−0.30%	16.16%	16.51%
Income						
< 20,000 euros	0.731	0.736	0.625	−0.67%	17.07%	17.86%
20.000–30,000 euros	0.691	0.700	0.606	−1.20%	14.01%	15.39%
> 30,000 euros	0.716	0.722	0.610	−0.75%	17.49%	18.37%
Education						
Lower than a high school diploma	0.722	0.725	0.600	−0.34%	20.48%	20.89%
High school diploma	0.710	0.716	0.618	−0.88%	14.85%	15.86%
Bachelor's degree	0.712	0.721	0.616	−1.23%	15.57%	17.00%
Master's/specialist degree	0.702	0.715	0.611	−1.76%	14.93%	16.98%
PhD/ Postgraduate specialization	0.686	0.685	0.584	0.03%	17.33%	17.29%

Note: $\Delta_{X-Y} = \left(\frac{Eff_X - Eff_Y}{Eff_Y}\right) * 100$ is the gain or loss of efficiency of model X compared with model Y.

efficiency gain for consumers in the higher income bracket, with an efficiency gain of approximately 13.5%.

Concerning education, it is interesting to highlight that when controlling only for the SBI input, the most efficient consumers are those who have qualifications lower than a high school diploma; when controlling for the MAI input, the consumers with a high school diploma are the most efficient ones. Finally, when controlling for the FWCI input, consumers with a Bachelor's degree are the most efficient. Table 6 shows the efficiency scores of the models resulting from the combination of two inputs. Overall, the stronger SBI input effect over the other inputs in guiding consumers to more efficient choices concerning spending on food is confirmed. Furthermore, focusing only on the most interesting results, concerning gender, the models that include the SBI input generate an efficiency advantage for females only in model IV, including MAI as an additional input. In the other two models, the average efficiency score is higher for males.

Finally, Table 7 shows a comparison of the complete model (model VII), including all three inputs, with the other models. The mean efficiency scores

Table 7. Efficiency scores of model VII by socio-demographic and economic characteristics and gain or loss of efficiency when comparing this model to each of the other ones.

Variable	model VII	Δ_{VII-I}	Δ_{VII-II}	$\Delta_{VII-III}$	Δ_{VII-IV}	Δ_{VII-V}	Δ_{VII-VI}
Gender							
Male	0.744	30.11%	18.10%	25.31%	5.19%	3.92%	18.02%
Female	0.736	35.09%	13.94%	31.74%	3.67%	2.99%	23.82%
Children aged under 12							
Yes	0.736	35.09%	13.94%	31.74%	3.67%	2.99%	23.82%
No	0.751	33.53%	15.77%	29.13%	4.50%	3.36%	21.54%
Age							
18–24	0.700	28.95%	18.65%	23.09%	5.46%	4.21%	16.67%
25–34	0.716	28.12%	17.92%	26.55%	4.40%	4.53%	17.80%
35–44	0.731	32.10%	16.04%	27.44%	4.53%	3.37%	20.49%
45–54	0.731	33.75%	15.98%	28.26%	4.69%	3.24%	20.85%
55–64	0.775	34.57%	14.99%	30.49%	4.03%	3.17%	22.66%
65–75	0.769	35.12%	14.08%	32.15%	3.89%	2.85%	24.25%
Macro area							
North-west	0.751	32.86%	15.76%	29.61%	4.23%	3.43%	21.35%
North-east	0.760	30.76%	16.85%	26.65%	4.63%	3.58%	19.68%
Centre	0.739	31.41%	17.25%	25.81%	5.10%	3.69%	18.97%
South	0.722	34.32%	14.72%	30.61%	3.96%	3.23%	22.61%
Family Size							
1	0.755	38.24%	15.48%	29.89%	5.13%	2.55%	24.02%
2	0.764	34.58%	15.22%	30.52%	4.37%	3.06%	22.47%
3	0.738	31.46%	15.99%	27.68%	4.31%	3.64%	19.98%
4	0.734	28.66%	17.92%	24.71%	4.59%	4.33%	17.88%
5+	0.662	30.93%	15.44%	29.60%	3.86%	3.55%	20.64%
Income							
< 20,000 euros	0.761	33.05%	15.44%	29.66%	4.11%	3.42%	21.89%
20,000–30,000 euros	0.724	31.91%	16.70%	26.48%	4.79%	3.54%	19.48%
> 30,000 euros	0.746	33.23%	15.26%	30.85%	4.10%	3.32%	22.31%
Education							
Lower than a high school diploma	0.749	34.73%	14.23%	33.46%	3.69%	3.34%	24.93%
High school diploma	0.742	31.88%	16.44%	27.76%	4.52%	3.61%	20.04%
Bachelor's degree	0.745	33.54%	15.87%	27.27%	4.58%	3.30%	20.86%
Master's/specialist degree	0.736	33.54%	16.04%	26.55%	4.83%	2.98%	20.48%
PhD/Postgraduate specialization	0.710	30.53%	15.18%	32.33%	3.62%	3.65%	21.57%

Note: $\Delta_{X-Y} = \left(\frac{Eff_X - Eff_Y}{Eff_Y}\right) * 100$ is the gain or loss of efficiency of model X compared with model Y.

of model VII are higher than those observed in the other models. The greatest efficiency gains are achieved when a model is compared with model I (where the input included is MAI), while the lowest values are achieved when a model is compared with models IV and V (models that both include the SBI input). Specifically, the efficiency gains reach their minimum values when a model is compared with model V, showing that since models IV and V both have the SBI input, the FWCI has greater effectiveness in reducing FW compared with that of the MAI input.

V. Discussion

This study exhibits two aspects of originality to be highlighted, on both a theoretical and methodological level. On the one hand, we have developed a microeconomic model whose objective is the minimization of a loss function linked to FW. To our knowledge, this is the first study that uses a loss function rather than a utility function. This is an element that distinguishes our work from previous ones, deriving the domestic FW rate that maximizes the consumer's utility function (see Drabik, de Gorter, and Reynolds 2019). Additionally, we have applied a DEA to the efficient choices of a consumer whose goal is to minimize FW. In this regard, the application of a DEA to the problem of efficient consumer choices in the past mainly concerned the analysis of the product launch (e.g. cars) capable of maximizing the consumer's utility (Blakrishnan, Nataraajan, and Desai 2000).

The DEA results confirm that FW is a complex issue, affected by both behavioural and psychological factors that influence each other (Principato et al. 2021; Quested et al. 2013). Indeed, using all three indices (inputs) simultaneously result in efficient consumer choices. The SBI input shifts the distribution farther to the right of the origin (guaranteeing a higher average efficiency), while the MAI and FWCI inputs shift probability mass to the right tail of the distribution (guaranteeing

a greater number of consumers who reach full efficiency).

In the models that included one of the inputs, the results showed that the SBI index generates a higher average efficiency score. This is in line with prior literature that highlighted the role of behavioural factors in different EU countries, particularly those related to shopping routines and habits (Bravi et al. 2020; Janssens et al. 2019; Mondéjar-Jiménez et al. 2016; Ponis et al. 2017; Romani et al. 2018; Secondi, Principato, and Laureti 2015; Stancu, Haugaard, and Lähteenmäki 2016). Therefore, in line with Janssens et al. (2019), we conclude that lack of planning is one of the most significant barriers to reducing FW. This result has important implications for FW comparison and prevention strategies and suggests that education and communication campaigns could be implemented to encourage consumers to use good practices in planning their food-shopping and avoid buying unnecessary food. In this regard, according to Aschemann-Witzel et al. (2015), it might also be useful to generate synergies in the actions of the public and private sectors, by combining, for example, public education campaigns with private retailers' initiatives aimed to improve consumers' planning skills. In this regard, some national retailers in Italy (e.g. Coop and Conad) already use their websites to offer practical and useful advice for their customers on planning food purchases. Furthermore, the results show that the interaction between SBI and FWCI encourages consumers to act more efficiently, in the sense of minimizing FW and efficiently using their income share for food consumption. Conversely, other researchers find only a weak relationship between environmental concerns and intentions to reduce FW (Janssens et al. 2019; Stancu, Haugaard, and Lähteenmäki 2016). This suggests that concerns indirectly affect FW behaviour, and the more consumers are concerned about FW, the more inclined they are to adopt positive behaviours that could reduce FW generation (i.e. planning food-shopping and routines) (Janssens et al. 2019; Principato, Secondi, and Pratesi 2015). Therefore, educational campaign implementations aimed at raising public awareness about the negative environmental and social consequences of FW could encourage consumers to plan their food purchases better.

Regarding the socio-demographic variables, the SBI notably creates a greater efficiency gain for women than for men, confirming the greater propensity of women to plan their shopping routines (Cantaragiu 2019; Cecere, Mancinelli, and Mazzanti 2014; Sarić et al. 2020; Secondi, Principato, and Laureti 2015). However, a new insight that our results could offer to the existing literature is that, given the same SBI level, men's efficiency levels are more affected by the influence of concerns. This could suggest that men are more receptive to public initiatives aimed at raising awareness about the FW impacts. Consequently, men should be a priority target in education campaigns that focus on the environmental and social impacts of waste.

Additionally, our results show that older consumers have higher efficiency scores because they are more likely to plan their purchases, confirming previous evidence (Bilska et al., 2020; Principato et al. 2021; Stancu, Haugaard, and Lähteenmäki 2016). Consequently, younger consumers, who are less inclined to plan their food purchases, should be the main target of public and private initiatives to encourage FW reduction. In this regard, given the greater propensity of young people to use new technologies, the diffusion of menu and shopping planning apps or apps to manage provisioning could efficiently act as a self-regulatory tool for this age group (Farr-Wharton, Choi, and Foth 2014; Jones 2016; Romani et al. 2018).

Concerning family size, the maximum efficiency score for the SBI index occurs for families with a small number of members, and decreases for large families, confirming the previous studies' results (Stancu, Haugaard, and Lähteenmäki 2016; Visschers, Wickli, and Siegrist 2016). This contrasts with Hanssen, Syversen, and Stø (2016), who found no significant differences in the amount of edible FW per person among households of different types, sizes, and age structures. However, an interesting insight from our results is that the SBI index generates a greater efficiency effect on consumers who have children aged under 12 in their households. This could be due to parents'

time constraints (Visschers, Wickli, and Siegrist 2016), children's unpredictable food preferences (Jörissen, Priefer, and Bräutigam 2015; Neff, Spiker, and Truant 2015), or the evidence that households with children tend to cook more often than households without children (Ponis et al. 2017). Consequently, our results suggest that families with children should be the main target of anti-waste information and education campaigns to improve their food-shopping and planning behaviour.

In line with the findings of previous studies (Principato, Secondi, and Pratesi 2015; Qi and Roe 2016; Sarić et al. 2020) we also found that income has a significant effect on the FW level; indeed, in our results, consumers with lower family income achieve the highest efficiency scores in all the models considered.

Our results also show the mediating role of education in influencing the effect of the three deterrence indices. However, in line with previous research (Bilska, Tomaszewska, and Kołożyn-Krajewska 2020; Janssens et al. 2019; Secondi, Principato, and Laureti 2015) considering only the SBI input, consumers with lower education are more efficient in FW generation. However, when controlling for the MAI and FWCI input, the most efficient consumers are those with a higher educational level. A new insight that we can draw from these results is that consumers with lower educational levels are more pragmatic and more sensitive to the influence of behavioural aspects. Conversely, consumers with higher educational levels are more influenced by psychological factors and exhibit higher concern and guilt levels about the food they waste.

Finally, it is interesting that the residence's geographical area also affects the efficiency scores for waste, highlighting a greater efficiency in the food-shopping behaviour of Northern consumers (both in the North-east and North-west). Differences among geographic areas were also funded in previous studies that highlighted differences in FW generation among people living in urban and rural areas (Hanssen, Syversen, and Stø 2016; Secondi, Principato, and Laureti 2015). This could suggest that policymakers should consider these marked differences in socio-demographic characteristics when designing or improving their programmes and initiatives aimed at reducing household FW.

VI. Conclusion

Our results, on the one hand, confirm that FW at the household level is affected by multiple drivers, including behavioural and psychological factors, and on the other hand, they highlight that the drivers have different levels of efficiency in reducing FW with reference to gender, age, family composition, and educational attainment. Therefore, our results strongly support the need to implement tailored educational and information campaigns that consider the most important targets identified, such as large families with children, young people, and men. Customizing the contents and tools used for these groups could generate greater effects in the fight against FW. At the same time, these strategies should be implemented with the strong involvement of local policymakers and institutions that can properly calibrate their interventions and tools to the local socio-economic reality.

However, an effective action to reduce waste at the household level is, as highlighted by Mourad (2016), only part of the solution to the problem, which instead requires prevention based on holistic changes in the food system.

Concluding it has to be highlighted that the presented findings have several limitations, mainly connected to the use of a web-based survey, prone to social desirability bias. As stressed by Giordano, Alboni, and Falasconi (2019), self-assessment of FW behaviour may lead to an underestimation of actual household FW. To overcome this limitation, further research should implement using diaries as a method for measuring household FW or matching the use of survey data with waste compositional analysis (Hanssen, Syversen, and Stø 2016). Additionally, as previous research highlighted differences among countries in FW behaviour at households' level (Mourad 2016; Secondi, Principato, and Laureti 2015), further research could replicate the survey in different countries, to analyse how cultural differences influences FW drivers.

As recommendations for further research, our microeconomic models could be tested considering the income destined for food consumption and the

monetary dimension of FW. However, in this context, the problems related to the interviewee's low propensity to provide accurate information on their 'bad' habits cannot be underestimated. Asking for a precise FW measure, expressed in monetary terms, bring the interviewee face to face with his or her unethical and not pro-environmental behaviour, and the risk is of a downward distorted figure being reported in high.

Last, another limitation is related to the DEA methodology. On the one hand, the DEA allows having a dimension of the consumer's degree of efficiency, without having to define a specific functional form that binds the inputs to the outputs; on the other hand, it does not allow for a dimension of the effect of the single inputs in the output determination. For this purpose, a parametric analysis method, such as stochastic frontier analysis, could be used. This method allows for obtaining the magnitude and sign of the parameters associated with the inputs and at the same time provides an efficiency measure linked to individual consumers. A future research target could be to implement a stochastic frontier analysis to our data and to verify which input primarily determines a wise food consumption choice.

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Appendix

Shopping Behaviour Index (SBI)	Weights
I like shopping for food	0.087
I usually plan food purchases by making a shopping list	0.096
I usually check the existing provisions before shopping	0.086
I usually decide what to buy only when I am at the supermarket	0.178
I usually purchase food that I did not include in the shopping list	0.031
I usually buy larger amounts of food when supermarkets offer good value for money	0.092
I usually buy food products close to their expiry dates in special offers	0.117
I like to try new foods that I have never tasted	0.097
For me, the freshness of food products is very important	0.068
I always pay attention to the quality/price ratio	0.079
I always compare the appearance of different products before buying them	0.070
Food Waste Concern Index (FWCI)	
Waste of environmental resources (water, energy, soil, etc.)	0.151
CO2 emissions increase due to the production and transport of food	0.175
Waste of economic resources for the purchase of food that is not consumed	0.168
Inequalities in food distribution among the world's population	0.168
Loss of biodiversity and desertification linked to intensive food production	0.173
Waste of economic resources linked to policies for the disposal of food surpluses	0.164
Moral Attitudes Towards Index (MAI)	
Wasting foods makes me feel sorry or guilty	0.103
I feel guilty about people who do not have enough food	0.158
I feel guilty for wasting environmental resources	0.186
I feel guilt for contributing to environmental pollution	0.201
I feel sorry for wasting money	0.153
I feel sorry for wasting time buying and preparing food	0.198
Wise Food Consumption Index (WFCI)	
How often are the following categories of food discarded in your household each week?	
Milk	0.114
Dairy products	0.101

(*Continued*)

(Continued).

Shopping Behaviour Index (SBI)	Weights
Bread	0.094
Bakery products	0.127
Fruits and vegetables	0.073
Meat/fish	0.123
Cold cuts	0.121
Rice/pasta	0.130
Sauces	0.117