Chapter 12
Multi-output Technical Efficiency in the Olive Oil Industry and Its Relation to the Form of Business Organisation

Rafaela Dios-Palomares, José M. Martínez-Paz, and Angel Prieto

Abstract This work studies the level of technical efficiency in the Andalusian oil industry from a multi-output, non-parametric approach by conducting the data envelopment analysis (DEA) methodology with non-radial distance functions, as well as implementing environmental and non-discretionary variables. The production frontier includes three outputs: quantity and quality of oil production, the outputs to be maximised, and one output to be minimised, the environmental impact of the production process. The inputs are the following: grinded olive, labour, and capital (both fixed and floating). The analysis is carried out by including non-discretionary variables from two points of view. It is considered that the business structure (cooperative or corporation) of the firm affects the frontier (technology). This variable is included through a specific three-stage method. The relation between efficiency and other non-discretionary variables is analysed by the estimation of a Tobit model. Having a sample of 88 oil-mill industries in Andalusia as the starting point, the indices for the two nonconventional outputs in this type of analysis are elaborated; quality is quantified by means of an aggregated index that gathers some aspects related to the separation of olives, critical points, and traceability. The environmental impact is assessed by another index that includes the effects produced on soil, water, air, and sound comfort. From the analysis of results, it can be underlined that, in spite of the fact that the levels of efficiency are high

R. Dios-Palomares (✉)
University of Córdoba, Campus de Rabanales, Córdoba, Spain
e-mail: rdios@uco.es

J.M. Martínez-Paz
University of Murcia, Campus Espinardo, Murcia, Spain
e-mail: jmpaz@um.es

A. Prieto
IRNASA. CSIC, Salamanca, Spain
e-mail: angel.prieto@irnasa.csic.es

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on average, some production adjustments to reduce inputs and the environmental impact of the process could be implemented. The influence of the business structure is significant, and results show that corporations are the most effective ones.

Keywords Olive oil • Cooperative • DEA • Technical efficiency • Hyperbolic distance • Environmental impact • Non-discretionary variables

12.1 Introduction

Olive oil is a product of particular importance within the Mediterranean agricultural food system, and more specifically in Spain, owing to two main reasons: first, because olive oil is an essential component of the so-called Mediterranean diet and, second, because Spain, and Andalusia in particular, is the world's main production area; over the last 10 years (2001–2010) around 39% of the olive oil produced worldwide is Spanish in origin, and over 79% of this oil comes from Andalusia (Rallo 2010).

The olive oil production industry, which is the object of this study, is the core of a production chain that starts in the olive sector, the producer of olives, and ends at the olive oil packaging and marketing sector. This production area is highly regulated by the EU Common Agricultural Policy (CAP) through the common organisation of the market in olive oil, pursuant to Commission Regulation (EC) 136/66, and its successive reforms in 1998 (Commission Regulation (EC) 1638/98), 2004 (Commission Regulation (EC) 865/2004), and 2007 (Commission Regulation (EC) 1234/2007). These regulations follow the trend put forward by the CAP reform in 1992. It tends towards the gradual reduction of direct support to production, which is the reason why the oil industry must necessarily increase its direct profitability. Thus, efficiency and productivity levels have to increase, and trade policies devoted to open new competitive markets have to be put into practice in order to compensate for the continuing decrease in support, which will take place in the near future (Mili 2009). The social, financial, and environmental importance of the olive sector in Spain, and especially in Andalusia, is a widely known and researched issue (Sánchez et al. 2011). Nearly 90% of all olive production (Rallo 2010) is used to produce oil, which means that the future of the olive sector is closely related to and conditioned by the future of its extraction industry. Therefore, the improvement of the industrial production processes has a direct impact on the enhancement of the agricultural sector that provides the raw material.

There is a highly relevant and differential feature in this industry, namely, the existence of two types of business structures: cooperatives, made up by the olive producers themselves, who associate to create the extraction industry of their own production, and corporations, which are not linked to any olive grove owners and in most cases are part of big food companies that buy the raw material directly from the market. Given their special ownership structure, cooperatives (Brada and Méndez 2009) introduce a distinguishing factor in the management system of their inputs and outputs that is different from that in traditional companies (Soboh et al. 2009). Some of these differences are the periods for payment to clients and providers, the profit-sharing mechanism, productive investments, etc. (Cook 1995). Some authors point out that it is to be expected that cooperatives have a lower level of technical efficiency than corporate companies (Salazar and Galve 2008), owing to the elevated management costs of the labour factor, among others (Bartlett et al. 1992; Schmitt 1993). Other works hold that the democratic decision-making system might restrict efficiency due to the heterogeneous and, sometimes, clashing interests of the owners (Jensen and Meckling 1979). At an empirical level, there are some studies that show this negative relation (Piesse et al. 1996; Ferrier and Porter 1991; Barreiro et al. 2009; Barnes 2006), but there are others that find a positive relation between cooperativism and technical efficiency (Hart and Moore 1990; Hofler and Payne 1993; Maietta and Sena 2008), as well as some other works that do not establish any determining relations (Bonin et al. 1993; Jones 2007; Alonso and García 2009).

The efficiency in production has been analysed very often in the field of technical efficiency through the production frontier function, as well as in the field of assignative and economic efficiency, considering the frontier of costs or profits as the base. Nowadays, the most used methodologies for the efficiency estimation through the frontier function are the following: the mathematic programming by the data envelopment analysis or DEA (Cooper et al. 2004) and the so-called econometric frontier (Battese 1992). The average efficiency level of the sample and the efficiency index of each company can be estimated by using both methods.

The study of the efficiency in the agricultural sector has a long-standing tradition, and this can be seen in several meta-analyses: Bravo-Ureta and Pinheiro (1993), analysing 39 cases; Abdourahmane et al. (2001), gathering 51 estimations of technical efficiency from 32 works; or Bravo-Ureta et al. (2007), relating 167 studies on technical efficiency at farm level. In Spain, a large number of empirical applications have been carried out since the late 1980s. Many of them are included in Alvarez's work (2001). Dealing with the Spanish olive production sector, the recent works by Amores and Contreras (2009) are also relevant, as they analyse the efficiency of olive groves in Andalusia. On the other hand, Lambarraa et al. (2007, 2009) study the technical efficiency and the productivity increase in the Spanish olive groves. At the international level, the most important recent works are those by Giannakas et al. (2000), Tzouvelekas et al. (2001), Karagiannis et al. (2003), and Karagiannis and Tzouvelekas (2009). All of them deal with technical efficiency of the olive sector in Greece. There are few analyses on the efficiency of the oil-mill industry. Some of them are the ones performed by Millán (1986), Damas and Romero (1997), and Dios-Palomares and Martínez-Paz (2011).

The main goal of this research is to measure the technical efficiency of this sector, which is the previous step before assessing the improvement opportunities in the resource management of this industry. In order to achieve this goal, the indicators of the levels of environmental impact and quality control of the production process have been designed and constructed, since these two aspects are key factors for the future of the sector and to get a quality product that allows implementing differentiation and segmentation strategies of the market

(Gázquez and Sánchez 2009). On the other hand, these points are also crucial for the processes to be environmentally sustainable, as current administrative regulations state, because of the advantages of the competitive image, since consumers are even more aware of these issues (Mesias et al. 2011).

This work incorporates three types of nonconventional variables into the analysis, as well as the ones that take part in the production process. In the first place, the environmental impact is a variable included in the analysis as an output to be minimised, whereas quality is an output to be maximised. The estimation of the global efficiency is carried out by means of an envelopment analysis model with hyperbolic distance. Although this methodology (DEA environmental modelling) has been previously applied in other sectors by Ball et al. (2004) and Hernández-Sancho et al. (2000), among others, it has never been applied to the olive oil area.

In the second place, the effects of the form of business organisation (hereafter also referred to as FBO) are analysed taking into account that this variable has an impact in the frontier, meaning that cooperatives have a different production technology from that of trading companies. It is considered a non-discretionary variable for it to be included. Several works have tackled this issue from different points of view in order to solve the problem. Some of the most relevant ones are the following Banker and Morey (1986), Lozano-Vivas et al. (2002), Muñiz (2001), Fried et al. (1999, 2002), and Daraio and Simar (2005), for continuous variables. In our case, FBO is a categorical variable, and we applied a method that is wider than that by Charnes et al. (1981). Our three-stage process allows estimating the efficiency once the effect of this variable has been removed. The application of this system in the same sector is seen in Dios-Palomares et al. (2005). This research puts forward a new global approach where the analysis is conducted by taking both aspects into account at the same time. In this way, the three-stage method, thoroughly described in the next section, is implemented in order to correct the impact of FBO on efficiency by applying the environmental modelling with directional distances in each phase.

And last, this work also studies the impact that other non-discretionary, socioeconomic variables (like seniority, number of members, and so on) may have on efficiency. An econometric model is estimated to determine whether there are any relations between these variables and the resource management carried out by the company (efficiency). Given the special structure of the endogenous variable, the specification of a general linear model has been criticised in specialised literature (Simar and Wilson 2007). That is the reason why this work estimates a Tobit model. The conclusions of this relation allow suggesting several strategies to improve the efficiency levels of the sector.

After this introduction, this study goes on with the theoretical description of the methodology used to study efficiency. The third section deals with more specific methodological aspects such as the source of the data, the construction process of the quality and environment indicators, or the formulation of the efficiency model. Results are shown in the following section, and the final one includes a summary and the conclusions of this study. The bibliography is in the last section of the document.

12.2 Methodology

In this section, the theoretical foundations of the efficiency model applied in this work are introduced. This model is a DEA with a hyperbolic distance function and environmental, categorical, and non-discretionary variables. To get this, the efficiency measuring methodology is combined with environmental non-discretionary variables (Dios-Palomares et al. 2006), with non-radial distance functions (Prieto and Zofío 2004), which allows to simultaneously include both the minimisation of the undesirable output and the effect of different technologies in the efficiency index of each company.

12.2.1 Characterising the Environmental Production Possibility Set

The conventional measurement of efficiency deriving from the original partially oriented output or input DEA models is not well suited to assess performance in an environmental framework, where undesirable outputs are produced. The reason is the radial equiproportional expansion of both sets of outputs – desirable and undesirable – in a "business as usual" strategy.[1] Nevertheless, since the work by Färe et al. (1989), it is possible to make use of the so-called hyperbolic distance function that considers both outputs asymmetrically by expanding the desirable outputs while reducing the undesirable outputs, marketed or not (Baumgärtner (2004)), giving rise to what is now known as DEA environmental modelling.

The definition of the hyperbolic distance function allows characterising the technology in a joint-production setting that is based on physical thermodynamic laws and, therefore, accounting for the non-separability between both sets of desirable and undesirable outputs, that is, null jointness is a necessary assumption for the production technology (Faber et al. 1998).[2] DEA environmental modelling allows establishing control and management programmes of contaminants and pollutants based on best practice criteria. This methodology is well developed in Ball et al. (1994, 2004), Hernández-Sancho et al. (2000), Zaim and Taskin (2000), Färe and Grosskopf (2004), Zofío and Prieto (2001), Prieto and Zofío (2004), Zaim (2004), Zhou et al. (2007), and Picazo-Tadeo and Prior (2009).

The formulation of the undesirable output reduction and the desirable output expansion in a joint-production framework by way of programming techniques has been accomplished by means of two hypotheses. These characterise the

[1] Actually CCR and BCC models cannot be applied in this case. The direction to the frontier of desirable outputs must differ from that of undesirable outputs.

[2] "The concept of joint production captures essential physical aspects of production. To this end, we want to link the economic concept of joint production to the laws of thermodynamics, and in particular the Entropy Law", p. 132.

environmental production possibility set, defining a joint environmental technology (Färe et al. 2005) that can be implemented through its environmental DEA counterpart (Zhou et al. 2007). This formulation leads to a specific method of modelling the undesirable outputs that comes from the traditional DEA structure that deals with them as though they were inputs, as in Hailu and Veeman (2001), Seiford and Zhu (2002), and Färe and Grosskopf (2004).[3]

To present our DEA model and assess environmental performance in the olive oil-mill industry, we first introduce the required concepts and notation. Let us assume that there exists a production process that transforms a vector of inputs $x = (x_1, \ldots, x_N) \in R_+^N$ into a vector of outputs $y = (y_1, \ldots, y_M) \in R_+^M$, which can be partitioned into two desirable and undesirable output subvectors: $p = (p_1, \ldots, p_P) \in R_+^P$ and $q = \left(q_1, \ldots, q_Q\right) \in R_+^Q$, respectively.

The environmental production possibility set is defined as

$$T = \{(p, q, x) \colon x \text{ can produce } (p, q)\}, \tag{12.1}$$

and it is assumed that T satisfies basic regularity properties: compact for each $x \in R_+^N$ – bounded and closed or interior, positive production cannot be possible without consumption inputs (i.e. free production is excluded) and free disposability of inputs and outputs (i.e. it is possible that an increase in inputs cannot originate an increase in outputs); see Färe et al. (1985) for its axiomatic formulation.

The technology set T can be equivalently expressed in terms of the output correspondence:

$$x \to P(x) \subseteq T_+^M, \quad M = P + Q, \tag{12.2}$$

where $P(x)$ denotes all (p, q) output vectors that can be produced by using the x input vector.

Given the regularity conditions of T, allowing $P(x)$ to represent an environmental production possibility set requires the assumption that it is not possible to produce q without p (i.e. the null jointness assumption):

1. If T allows for the joint production of (p, q) from a given vector x, then

$$(p, q) \notin P(x), \quad \forall q = 0, \quad p \neq 0; \quad \text{or} \quad (p, q) = (0, 0) \in P(x). \tag{12.3}$$

2. If for a given vector x, it is not possible to reduce q without reducing p, then the reduction of q bears a cost on p (i.e. a technological opportunity cost). This assumption is formally introduced by considering that q is weakly disposable with regard to p:

[3] The proposal to treat undesirable outputs as inputs by DEA can lead to undesirable outputs without desirable outputs, (Zhu 2009), violating the null jointness assumption. This treatment is compiled by using appropriate mathematical programming techniques in the context of DEA models without outputs (Lovell and Pastor 1995).

$$\text{If } (p, q) \in P(x) \Rightarrow (\lambda p, \lambda q) \in P(x), \quad 0 < \lambda \leq 1. \tag{12.4}$$

When a specific industrial technology requires it, we can also allow for free disposability for p and x:

$$\text{If } p \in P(x), \quad p \geq p' \Rightarrow p' \in P(x), \quad \text{and} \tag{12.5}$$

$$\text{If}(p, q) \in P(x), \quad x' \geq x \Rightarrow (p, q) \in P(x'), \tag{12.6}$$

the output vector (p, q) produced by a smaller input vector also belongs to the production possibility set associated to a larger input vector.

For performance measurement purposes, we can define two alternative subsets in the environmental production possibility set, $P(x)$ – satisfying properties (12.3) and (12.4):

$$\text{Isoq } P(x) = \{(p, q): (p, q) \in P(x), \lambda > 1, (\lambda p, \lambda q) \notin P(x)\}, \tag{12.7}$$

it is not possible to increase (p, q) for a given x, but it is possible to increase (or to diminish) q for a given p, and

$$\text{Eff } P(x) = \left\{(p, q): (p, q) \in P(x), (p', q') \geq (p, q) \Rightarrow (p', q') \notin P(x)\right\} \tag{12.8}$$

From (12.7) and (12.8), it is possible to see that for any vector,

$$(p', q'), p' \geq p, q' \leq q \Rightarrow (p', q') \notin P(x).$$

Assumption (12.3) means that the projection towards the origin of any observed output vector (p, q) belongs to the production possibility set, and therefore, in the limit of that projection, the origin belongs to it, while (12.4) assumes that activity in the undesirable output axis is not possible.

12.2.2 The Hyperbolic Measure of Environmental Productive Performance

Once the environmental production possibility set $P(x)$ has been defined, our interest focuses on how to measure the distance separating any decision unit from the production frontier of $P(x)$. Färe et al. (1985) introduced the hyperbolic distance function (HD) in order to measure the possibility of expanding the desirable outputs while reducing the inputs at the same time. They called it hyperbolic because the asymmetric projection path towards the production frontier corresponds to that definition, constituting a generalisation of the partially radial distance functions. The seminal work by Färe et al. (1989) adapts this setting to the environmental case by replacing the undesirable output vector q for the input vector x, allowing for equiproportional undesirable output reduction and desirable output expansion. In this vein, the main advantage of the hyperbolic measurement framework is that it accommodates the relevant environmental information such as the change in the ratio p/q.

To empirically determine the efficient frontier and to calculate the efficiency scores reflecting the environmental behaviour of the firms, we assume that there exist observations $k = 1, \ldots, K-$DMU's in the operations research literature. For a particular firm "o", $P(x)$ is defined as

$$P\left(x_{\mathrm{o}}\right) = \left\{(p,q) \colon \sum_{k=1}^{K} z_k p_{kp} \geq p_{oq}, \sum_{k=1}^{K} z_k q_{kq} = q_{oq}, \sum_{k=1}^{K} z_k x_{kn} \leq x_{on}, z_k \in R_{+}^{K}\right\}, \tag{12.9}$$

where z_k are intensity variables for the different linear combinations, which therefore represent weights for each k in $P(x_{\mathrm{o}})$.

It is assumed that the degree of efficiency of every firm corresponds to the value of the hyperbolic distance function (HD):

$$\mathrm{DH}(p,q) = \max\left\{\theta : \left(\theta p, \frac{q}{\theta}\right) \in P(x), \quad \theta \geq 1\right\} \tag{12.10}$$

From (12.9) and (12.10), the environmental DEA efficiency score for each company k can be calculated by solving

$$\begin{aligned} &\mathrm{DH}\left(p_{\mathrm{o}}, q_{\mathrm{o}}, x_{\mathrm{o}}\right) = \max_{z\theta} \theta \\ &Pz \geq \theta p_{\mathrm{o}} \\ &Qz = \frac{q_{\mathrm{o}}}{\theta} \\ &Xz \leq x_{\mathrm{o}} \\ &z \geq 0 \end{aligned} \tag{12.11}$$

Where $\theta \geq 1$,

- $z = (z_1, z_2, \ldots, z_K)^t \in \Re^K$.
- $P = (p_1, p_2, \ldots, p_K) \in \Re^{P \times K}$ is a $P \times K$ matrix of desirable outputs (with $p_j \in \Re^P$ the data vector of the output values at DMU_j).
- $Q = (q_1, q_2, \ldots, q_K) \in \Re^{Q \times K}$ is a $Q \times K$ matrix of undesirable outputs (with $p_j \in \Re^Q$ the data vector of the output values at DMU_j).
- $X = (x_1, x_2, \ldots, x_K) \in \Re^{N \times K}$ is a $N \times K$ matrix of inputs (with $x_j \in \Re^N$ the data vector of the input values at DMU_j).

Equation (12.11) corresponds to a model specified under the assumption of constant returns to scale (CRS). Variable returns to scale[4] can be imposed by adding the following restriction:

$$\sum_{k=1}^{K} z_k = 1$$

Comparing the solutions to both models, we can analyse the impact of the productive scale in the level of efficiency.

These models do not distinguish between (12.7) and (12.8) and do not exclude the possibility of increasing (or reducing) q for a given p; desirable output and input slacks may exist, implying non-equiproportional reduction in p. This problem can be tackled by adopting a two mathematical programming approach (Ali and Seiford 1993). In fact, slacks can be calculated by solving the following second-stage problem:

$$\begin{aligned}
&\max_{z, S_p^+,\, S_q^-, S_x^-} S_p^+ + S_q^- + S_x^- \\
&Pz - S_p^+ = \theta^e p_o \\
&Qz + S_q^- = \frac{q_o}{\theta^e} \\
&Xz + S_x^- = x_o \\
&z \geq 0
\end{aligned} \tag{12.12}$$

where S_p^+, S_q^-, S_x^- stand for the outputs p, q, and input slacks and θ^e is the efficiency score obtained when solving (12.11).[5]

12.2.3 The Three-Stage Programme Method

Once the environmental production possibility set $P(x)$ and hyperbolic measure of environmental productive performance with respect to the frontier have been defined, our aim is to estimate the efficiency level regarding the undesirable outputs by taking non-discretionary variables into account as well. Our method is developed in three stages in order to isolate the effect of these variables.

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[4]It is possible to go deeper in the concepts of returns to scale in Cooper et al. (2004), Chapter 2, p. 41.

[5]Expression (12.11) is not linear because of the second set of restrictions, but it is easily computable in non-linear programming. All these models were specified in MATLAB using the non-linear optimiser "fmincon" – find minimum of a constrained non-linear multivariate function.

12.2.3.1 Estimation of Environmental Efficiency Regarding a Categorical Non-discretionary Variable

To describe the applied method, we consider the case of a dichotomous, non-discretionary variable without loss of generality. The method is addressed to a group of K companies, where the variables to consider in the efficiency analysis are P desirable outputs (p_p), Q undesirable outputs (q_q), and N inputs (x_n), with a dichotomous, non-discretionary variable z with values z_h for $h = a,\ b$. Regarding this variable, the sample is divided into two subsamples, K_h in size, and their data matrices would be for each subsample h (*for* $h = a, b$)*:*

- $P_h = \left(p_{1h}, p_{2h}, \ldots, p_{K_h h}\right) \in \Re^{P \times K_h}$ is a $P \times K_h$ matrix of desirable outputs (with $p_{kh} \in \Re^P$ the data vector of the output values at DMU$_{kh}$ belonging to the subsample where $z_h = h$).
- $Q_h = \left(q_{1h}, q_{2h}, \ldots, q_{K_h h}\right) \in \Re^{Q \times K_h}$ is a $Q \times K_h$ matrix of undesirable outputs (with $p_{kh} \in \Re^Q$ the data vector of the output values at DMU$_{kh}$ belonging to the subsample where $z_h = h$).
- $X_h = \left(x_{1h}, x_{2h}, \ldots, x_{K_h h}\right) \in \Re^{N \times K_h}$ is a $N \times K_h$ matrix of inputs (with $x_{kh} \in \Re^N$ the data vector of the input values at DMU$_{kh}$ belonging to the subsample where $z_h = h$).

Next the method is analysed by describing its three stages.

I. *Stage One*

The sample is divided into the two different subsamples for $h = a$ and $h = b$, and a frontier is estimated for each of them, applying the expressions (12.11) and (12.12), which allows achieving the HD function for the environmental DEA model with the aim of obtaining the intra-group efficiencies, which are named

$$\theta_{kh} \text{ for } kh = 1, \ldots, K_h, \text{ and } h = a, b \text{ and the slacks } S^+_{pkh}, S^-_{qkh} \text{ and } S^-_{xkh}.$$

From now on, we substitute the observed data values for their target values (projected onto the frontier), each one in its corresponding subsample. By doing this, we eliminate inefficiency that is relative to each unit in its group. New values for outputs and inputs are calculated for each value of h (a and b), according to the following correction:

$$\begin{aligned}
P_h{}^* &= \left(p^*_{1h}, p^*_{2h}, \ldots, p^*_{K_h h}\right) \in \Re^{P \times K_h} \quad \text{with} \quad p^*_{kh} = p_{kh}\theta_{kh} + S^+_{pkh} \quad \text{and} \quad k = 1 \ldots K_h \\
Q_h{}^* &= \left(q^*_{1h}, q^*_{2h}, \ldots, q^*_{K_h h}\right) \in \Re^{Q \times K_h} \quad \text{with} \quad q^*_{kh} = \frac{q_{kh}}{\theta_{kh}} - S^-_{qkh} \quad \text{and} \quad k = 1 \ldots K_h \\
X_h{}^* &= \left(x^*_{1h}, x^*_{2h}, \ldots, x^*_{K_h h}\right) \in \Re^{N \times K_h} \quad \text{with} \quad x^*_{kh} = x_{kh} - S^-_{xkh} \quad \text{and} \quad k = 1 \ldots K_h.
\end{aligned} \tag{12.13}$$

p_{kh}, q_{kh}, and x_{kh} being the original values.

II. *Stage Two*

A new frontier is estimated using the complete K-sized sample, but considering the following transformed (targets) data calculated in stage one:

$$\begin{aligned} P^* &= \left(p^*_{1a}, p^*_{2a}, \ldots, p^*_{K_a a}, p^*_{1b}, p^*_{2b}, \ldots, p^*_{K_b b}\right) \in \Re^{PxK} \quad \text{with} \quad p^*_{kh} \in \Re^P \\ Q^* &= \left(q^*_{1a}, q^*_{2a}, \ldots, q^*_{K_a a}, q^*_{1b}, q^*_{2b}, \ldots, q^*_{K_b b}\right) \in \Re^{QxK} \quad \text{with} \quad q^*_{kh} \in \Re^Q \\ X^* &= \left(x^*_{1a}, x^*_{2a}, \ldots, x^*_{K_a a}, x^*_{1b}, x^*_{2b}, \ldots, x^*_{K_b b}\right) \in \Re^{NxK} \quad \text{with} \quad x^*_{kh} \in \Re^N \end{aligned} \tag{12.14}$$

Therefore, the HD function for the environmental DEA models (12.11) and (12.12) is applied again with the aim of obtaining new scores for the whole sample, which are called

θ^*_k for $k = 1, \ldots, K$, and the slacks S^{*+}_{pk}, S^{*-}_{qk}, and S^{*-}_{xk} are also calculated as a result of the optimisation process.

These estimated values represent, for each firm k, the distance from its target (p^*, q^*, x^*) in its own frontier group (a or b) to the overall frontier. Note that different distances imply different productivities due to the non-discretionary variable. The new overall targets will be

$$\begin{aligned} P^{**} &= \left(p^{**}_1, p^{**}_2, \ldots, p^{**}_K\right) \in \Re^{P\times K} \quad \text{with} \quad p^{**}_k = p^*_k \theta^*_k + S^{*+}_{pk} \quad \text{and} \quad k = 1 \ldots K \\ Q^{**} &= \left(q^{**}_1, q^{**}_2, \ldots, q^{**}_K\right) \in \Re^{Q\times K} \quad \text{with} \quad q^{**}_k = \frac{q^*_k}{\theta^*_k} - S^{*-}_{qk} \quad \text{and} \quad k = 1 \ldots K \\ X^{**} &= \left(x^{**}_1, x^{**}_2, \ldots, x^{**}_K\right) \in \Re^{N\times K} \quad \text{with} \quad x^{**}_k = x^*_k - S^{*-}_{xk} \quad \text{and} \quad k = 1 \ldots K \end{aligned} \tag{12.15}$$

and the effect due to the non-discretionary variable z is calculated by means of the following expressions:

$$\begin{aligned} \Delta P &= (\Delta p_1, \Delta p_2, \ldots, \Delta p_K) \in \Re^{P\times K} \quad \text{with} \quad \Delta p_k = p^{**}_k - p^*_k \\ \Delta Q &= (\Delta q_1, \Delta q_2, \ldots, \Delta q_K) \in \Re^{Q\times K} \quad \text{with} \quad \Delta q_k = q^{**}_k - q^*_k \\ \Delta X &= (\Delta x_1, \Delta x_2, \ldots, \Delta x_K) \in \Re^{N\times K} \quad \text{with} \quad \Delta x_k = x^{**}_k - x^*_k \end{aligned} \tag{12.16}$$

III. *Stage Three*

To eliminate the effect of the non-discretionary variable, the original data are transformed by using the incremental values calculated in (12.16) in the following way:

$$\begin{aligned} P^c &= \left(p^c_1, p^c_2, \ldots, p^c_K\right) \in \Re^{P\times K} \quad \text{with} \quad p^c_k = p_k + \Delta p_k \quad \text{and} \quad k = 1 \ldots K \\ Q^c &= \left(q^c_1, q^c_2, \ldots, q^c_K\right) \in \Re^{Q\times K} \quad \text{with} \quad q^c_k = q_k + \Delta q_k \quad \text{and} \quad k = 1 \ldots K \\ X^c &= \left(x^c_1, x^c_2, \ldots, x^c_K\right) \in \Re^{N\times K} \quad \text{with} \quad x^c_k = x_k + \Delta x_k \quad \text{and} \quad k = 1 \ldots K \end{aligned} \tag{12.17}$$

Then, the HD function for the environmental DEA models (12.11) and (12.12) is applied again to the data (12.17) with the aim of obtaining the real efficiencies, having removed the non-discretionary variable effect. The results of the optimisation process are the following scores:
θ_k^c for $k = 1, \ldots, K$ and the slacks S_{pk}^{c+}, S_{qk}^{c-}, and S_{xk}^{c-}.

12.2.3.2 Quantifying the Non-discretionary Effect

As we have already seen in the development of the method, the effect due to the non-discretionary variable is related to the estimated distance in stage two (θ^*). We define this effect by

$$\hat{E}_k = \left(\frac{1}{\theta_k^*}\right) \times 100 \quad \text{for} \quad k = 1, \ldots, K \tag{12.18}$$

In order to evaluate the impact of the non-discretionary effect between the two subgroups, we calculate for each subgroup $h = (a, b)$ the average of this effect, and therefore,

$$\hat{E}_a = \frac{1}{K_a} \sum_{ka=1}^{K_a} \hat{E}_{ka}, \quad \forall DMU_{ka} \in \text{subsample } (h = a), \quad \text{and}$$

$$\hat{E}_b = \frac{1}{K_b} \sum_{kb=1}^{K_b} \hat{E}_{kb}, \quad \forall DMU_{kb} \in \text{subsample } (h = b) \tag{12.19}$$

And then we calculate the environmental ratio:

$$\text{ER} = \frac{\hat{E}_a}{\hat{E}_b} \tag{12.20}$$

The magnitude of this ratio indicates the importance of the non-discretionary variable in the efficiency assessment process.

12.3 Data and Efficiency Model

12.3.1 Source and Elaboration of Data

The primary source of data is the official record of the 806 oil mills in Andalusia in 2005–2006. These data contain about 30 variables. The most relevant ones for our study are those related to oil production, quantity of processed olives, extraction system, storage and treatment of effluents, and form of business organisation, among others. This information has been completed with two complementary sources that are necessary for the analyses: (1) the companies accounting reports in the register of companies and cooperatives and (2) a survey elaborated for a sample of companies like the one under study, so as to find out more about other issues related to socioeconomic, quality, and environmental impact aspects. After the sampling and the data cleaning processes, the records of 88 oil-mill industries are considered valid and complete, and they make up the final sample used in this study, 11% of the total census.

With the aim of studying the quality level and the environmental impact of the production process, each phase of the technological process (transport, reception and storage of the olive, extraction, storage of oil, and management of effluents) has been analysed. The variables that must be gathered from each company are chosen in order to get an overall value for each index, quality, and environmental impact. Nevertheless, as there are several aspects to be borne in mind, it is also necessary to define the priority relations among them, so that they can be included in the index with a specific level of relevance. This sequence has been established according to the opinions of 16 experts and after the application of a two-wave Delphi method (Almansa and Martinez-Paz 2011) that has improved the grade of consensus, as it reduces the dispersion of answers. Through a regular ranking in a Likert scale (0 null importance – 5 maximum importance), the experts assessed a wide range of attributes related to quality and environmental impact in the production process (Rikkonen 2005). This ranking determines the relevance and weight of every attribute in the index. The values for these attributes in each company have been compiled from the above-mentioned direct surveys. And finally, efficiency and quality indices have been constructed and presented in the Results section. These indices gradually increase on the aspect evaluated in the 0–100 interval.

12.3.2 The Technical Efficiency Model

The variables used in the efficiency model are shown in Table 12.1. The first two outputs, production (oil) and quality level in the production (quality index), are desirable products, while the environmental impact of the production process (Environmental Impact Index) is an undesirable product. The formulated model maximises desirable outputs and minimises the undesirable output, given the inputs of olive, labour, and capital (fixed and floating). The categorical variable *FOB* is an environmental, non-discretionary variable that divides the sample into two subsamples (cooperatives and corporate companies, respectively).

The oil production corresponds to the period under study (2005–2006). There was an attempt to break down the production by qualities, but the data provided by the companies were neither homogeneous nor comparable among them.

The fact that we use staff costs instead of the usual, physical employment variable (worked hours, number of full-time employees, etc.) is because, although the reports in registers are systematic and precise, the data referred to labour is not

Table 12.1 Variables of the efficiency model

Outputs	Oil (ton)
	Quality index
	Environmental Impact Index
Inputs	Grinded olive (ton)
	Floating capital (€)
	Fixed capital (€)
	Staff costs (€)
Environmental non-discretionary variable	Form of business organisations (*FOB*): cooperatives or corporate firms

Source: Prepared by the authors

Table 12.2 Descriptive statistics of outputs and inputs

	Mean	St. dev.	Minimum	Maximum
Grinded olive (ton)	5, 530	5, 080	254	21, 482
Staff costs (10^3 €)	117	115	3	747
Floating capital (10^3 €)	3, 336	2, 940	177	12, 011
Fixed capital (10^3 €)	116	95	3	487
Oil (ton)	1, 644	1, 330	185	5, 229
Quality index	49.8	6.7	31.6	68.0
Environmental Impact Index	38.4	8.1	17.0	61.2

Source: Elaboration by the authors based on the surveys

homogeneous, and the reports use different methods to calculate this information, which makes this data unreliable and invalid for the model. In addition, there is no precise and systematic data on the quality of the labour factor. This lack has been made up by the incorporation of the second phase of the analysis with socioeconomic, non-discretionary variables that are related to the manager's training, the master's years of experience, and the temporary nature of the employment.

The floating capital has been measured by the total running and maintenance costs. This definition does not match the accounting concept of working capital (which is the current assets minus the current liabilities) but the operative concept of cash flow, meaning the consumable elements or goods in the production cycle of the firm. The fixed capital refers to the annual depreciation of the firm's fixed assets.

Prior to the efficiency analysis, a descriptive analysis of the involved variables has been carried out. Table 12.2 includes the description of oil production and the inputs of olive, labour, and capital with its two variables, floating and fixed capital.

In view of the results, a great variability in the magnitude of all variables can be observed. This is due to the fact that among the 88 oil mills under study, some of them are small and others are huge; therefore, the sample is balanced in the efficiency study according to this significant feature (Färe et al. 1994).

Table 12.3 shows a descriptive analysis of additional characteristics of the sample that will be considered in order to determine associative relations between the oil-mill profiles and the efficiency levels.

Table 12.3 Description of the socioeconomic non-discretionary variables

Continuous variables				
Variable	Mean	St. dev.	Minimum	Maximum
Age (years)	41.38	9.62	23	67
Master's seniority (years)	14.95	10.97	2	40
Proportion of permanent jobs (%)	61.21	21.45	15	100
Number of members (no.)	288	416	1	1, 800
Dichotomous variables				
Variable	Yes (%)	No (%)		
Manager's specialised training	61.1	38.9		
Agricultural association membership	75.3	24.7		
Marketing association membership	36.0	64.0		
Internet sales	15.7	84.3		
Cooperative association	45.5	54.5		

Source: Elaboration by the authors based on the surveys

Table 12.4 Differences in the mean inputs and outputs regarding *FBO*

Variable	Cooperatives	Corporate firms	Sig. t-test
Grinded olive (ton)	7, 354	4, 010	0.00
Staff costs (10^3 €)	134	103	–
Floating capital (10^3 €)	4, 648	2, 243	0.00
Fixed capital (10^3 €)	154	84	0.00
Oil (ton)	2, 181	1, 197	0.00
Quality index	50.7	49.1	–
Environmental Impact Index	39.1	37.9	–
N	40	48	

Source: Elaboration by the authors based on the surveys

There are four variables measured continuously to be considered: the employer's age, the mill master's seniority, the ratio between fixed and temporary workers (%), and the number of members of the company. Some dichotomous variables are also studied: the existence of a manager specialised in the mill industry, membership to any agricultural or marketing associations, Internet sales, and the legal form (cooperative or others).

Table 12.4 includes the analysis of the differences in the mean variables between the two groups of firms that form the sample (cooperatives and corporate companies). This aims at testing the need for introducing the *FOB* variable as an environmental, non-discretionary variable.

There are significant differences in the means of olive grinded and oil produced and in the capital used, both floating and fixed. These means are higher in cooperatives. Ratios between outputs and inputs in each group may illustrate the great differences in apparent productivity. Then, it is of interest for the efficiency study to include the *FBO* variable, which has to do with the business structure. It can be concluded that the frontier (technology) of cooperatives may differ from that of corporations.

12.4 Results

The efficiency level of oil mills has been calculated by the resolution of the method proposed in the Methodology section. Despite this score has been defined as $\theta \geq 1$ in (12.11), we present the results of the efficiency index evaluated as $0 \leq (1/\theta) \leq 1$, in order to handle a more intuitive measure.

Table 12.5 shows the descriptive statistics of the efficiency indices deriving from this method application, under the assumptions of constant returns (CRS) and variable returns (VRS) in the last stage. Scale efficiency, which is the quotient between technical efficiency and pure efficiency, as well as the percentage of efficient firms for each measurement, is also included in Table 12.5.

The average efficiency levels are high, although the technical efficiency minimum is 0.65. There is a great percentage (27.3%) of completely efficient firms both technically and in scale. Given the specification of the model, the inefficiency level, evaluated as the hyperbolic distance at each firm's frontier, determines the possible improvements that could be carried out to increase production and quality and diminish the environmental impact.

As explained in the Methodology section, the measures taken from the solution of the method show the efficiency levels once the business structure effect is corrected. They actually measure the levels of oil mills, good or bad performances in the management of resources, and the distance to the frontier is not attributable to any of the differential factors that are characteristic to both business organisations.

In this way, it is possible to quantify the effect of the *FBO* variable by applying expression (12.19) to both groups. Table 12.6 shows the mean values ($\hat{E}_{\text{coo}}$ and $\hat{E}_{\text{cor}}$) together with the environmental ratio ER, which is obtained by expression (12.20). The value of the latter is 11.29, meaning that there exists a wide distance between the frontiers of both groups. The least productive group is the one that has a greater mean effect, that is, in this case, the group of cooperatives. Moreover, the difference in the means between the effects of both groups has been contrasted, and it is significant (P value = 0.001).

Table 12.5 Basic statistics of the efficiency indices

	Minimum	Maximum	Mean	St. dev.	Efficient firms (%)
Technical (CRS)	0.65	1.00	0.91	0.09	27.3
Pure (VRS)	0.66	1.00	0.95	0.07	51.1
Scale (SCA)	0.74	1.00	0.96	0.06	27.3

Source: Elaboration by the authors

Table 12.6 Effect of the FBO variable in efficiency

Group	FBO effect (%)	ER
Cooperatives	3.50	11.29
Corporate firms	0.31	

Source: Elaboration by the authors

Table 12.7 Differences in efficiency means between the two groups

	Cooperatives	Corporate firms	Sig. *t*-test
Technical (CRS)	0.82	0.89	0.00
Pure (VRS)	0.91	0.92	–
Scale (SCA)	0.90	0.97	0.00

Source: Elaboration by the authors

Table 12.8 Distribution of efficiency by groups

(No)	Cooperatives	Corporate firms	Total
Total	40	48	88
Constant returns (CRS)			
Efficient	2	17	19
1st quartile	23	24	47
Under 1st quartile	15	7	22
Variable returns (VRS)			
Efficient	2	17	19
1st quartile	23	24	47
Under 1st quartile	15	7	22
Scale returns (SCA)			
Efficient	6	30	36
1st quartile	19	14	33
Under 1st quartile	15	4	19

Source: Elaboration by the authors

Once the existence of different frontiers has been detected, the need to include the *FBO* variable is clear. Otherwise, if we had not done so, the efficiency estimation would have biased the results against cooperatives.

Tables 12.7 and 12.8 gather a set of contrasts found between the two groups in order to go deeper in the analysis of the differences in efficiency. In the first place, Table 12.7 shows the differences in the means of the three efficiency measures. It is noticeable that the mean efficiency is higher for corporate firms both in constant and scale returns, whereas there is no statistically significant difference (although in the same direction as the other two) in the model of variable returns.

These results imply that, even after correcting the *FBO* effect (which does not depend on the own management of the firm), cooperatives still are less efficient than the rest of the sample (constant returns), also in scale, which means that they are not at their optimum size. Thus, we can affirm that cooperatives are less efficient than corporate firms, which supports the prevailing hypothesis in the existing literature to this respect. However, it must be highlighted that the special treatment given in this study to business structures in the efficiency assessment allows corroborating this assertion even more strongly than in other works that compare efficiency levels among groups with no frontier separation.

To finish the comparison of the efficiency levels between the two groups, we have examined the amount of firms in each group that belong to three different categories:

Table 12.9 Tobit estimation of the efficiency factors

Variables	Coeff.	Sign.
Constant	0.905	0.00
No of members	−0.008	0.14
Master's seniority	−0.003	0.07
Manager's training	0.006	0.08
Internet sales	0.003	0.09
Agricultural associations membership	0.007	0.15
Marketing association membership	0.056	0.09
Proportion of permanent jobs	−0.005	0.08
McFadden's pseudo R^2	0.356	

Source: Elaboration by the authors

totally efficient firms, inefficient firms having an index higher that the first quartile, and inefficient firms with an index lower than the first quartile. Table 12.8 shows the information related to the classifications prepared for the indexes of constant, variable, and scale returns, respectively.

Among the 19 totally efficient firms within the CRS index, only two of them are cooperatives, while 17 are non-cooperative business. Actually, there are a much higher proportion of cooperatives in the category of the least efficient firms. When it comes to the model of low variable returns (VRS), although the overall differences are not significant, the proportion of the distribution goes in line with the CRS index results: among the efficient businesses, there are more trading companies than cooperatives; whereas, among the inefficient ones above the first quartile, there are less trading companies than cooperatives. As for scale efficiency, similar conclusions are drawn.

Therefore, thanks to these comparative analyses, we can assert that efficiency levels are lower in cooperative associations, even after having corrected the structural difference that prevent them from having more productivity. This means that there is room for improving the management of cooperatives.

And finally, a second-stage analysis has been carried out so as to study the possible associations between the efficiency index and the socioeconomic characteristics of every firm that were not included as inputs or outputs in the frontier formulation. This analysis is aimed at finding out the impact of these variables in the index of technical efficiency. Due to the limited nature both on the top and bottom of the efficiency index, the selected method is a doubly censored Tobit regression model, which is the alternative to avoid biased estimators related to the use of OLS regressions with this kind of data (Simar and Wilson 2007). The socioeconomic, non-discretionary variables included in the model (see Table 12.4) have been contrasted to detect multicollinearity, which would also bias parameters (Freese and Scott 2006). The estimation results of the efficiency level are included in Table 12.9.

In sight of these results, considering the statistical signification level at 10% and the sign of their coefficient, we conclude that the most efficient oil mills are those that have a young master of operations, a manager trained in business management, Internet sales, membership to marketing associations, and a low proportion of permanent jobs.

12.5 Conclusions

This work studies the level of technical efficiency in the Andalusian oil industry from a multi-output, non-parametric approach by conducting the data envelopment analysis (DEA) methodology with non-radial distance functions, as well as implementing environmental and non-discretionary variables.

The production frontier includes three outputs: quantity and quality of oil production, the outputs to be maximised, and one output to be minimised, the environmental impact of the production process. The inputs are the following: grinded olive, labour, and capital (both fixed and floating).

The analysis is carried out by including non-discretionary variables from two points of view. It is considered that the business structure (cooperative or corporation) of the firm affects the frontier (technology). This variable is included through a specific three-stage method. The relation between efficiency and other non-discretionary variables is analysed by the estimation of a Tobit model.

Having a sample of 88 oil-mill industries in Andalusia as the starting point, the indices for the two nonconventional outputs in this type of analysis are elaborated; quality is quantified by means of an aggregated index that gathers some aspects related to the separation of olives, critical points, and traceability. The environmental impact is assessed by another index that includes the effects produced on soil, water, air, and sound comfort.

Among the oil mills under study, there are two groups that differ from each other in their business structures: 42% are cooperatives and the rest of them are corporate trading companies. The descriptive study on inputs and outputs carried out before the efficiency analysis leads to the hypothesis that both groups might have a different frontier, and this has been corroborated by the results obtained.

The efficiency levels found, once the effect of the form of business organisation has been corrected, are high on average, around 90%. However, there are firms that could increase their quality and production levels up to 40% and shrink the environmental impact up to the same percentage, without enhancing their industrial facilities. As for the scale efficiency, just 27% of firms are working at their optimum size. Nevertheless, scale inefficiency is not really high in oil-mill industries that do not work with constant returns.

We hold that the effect of the business structure is significant, which justifies the use of the suggested method. Regardless of the correction in the effect of the different frontier, cooperatives are less efficient than corporate companies. The problem of scale inefficiency presents the differences and then the chances for improvement plans in the clearest way. In this respect, Oustapassidis et al. (1998) hold that low scale efficiency in Greek dairy cooperatives is due to the fact that an excess of inputs is better accepted by cooperatives than by corporate companies because inputs come from their owners.

According to the results in the last stage and the existence of scale inefficiencies, collaboration agreements between firms are highly advisable. For instance, the externalisation of some processes like the product marketing and advertising is a model that deserves some attention in order to improve the sector's efficiency. This activity would create entities offering services to several companies and would facilitate the inclusion of two efficiency factors: on-line sales and business management experts. The reason why the inclusion of masters with less seniority is also a symptom of more efficiency could be the fact that training and updated knowledge are more useful than experience in techniques and processes when it comes to managing resources in an efficient way.

The fact that the labour temporality is a factor that enhances efficiency could be striking. But flexibility in the number of employees is crucial when planning an efficient allocation of resources, owing to the special features of this extraction industry, such as the important seasonal component.

There is no doubt that the special idiosyncrasy of cooperative entities, where employer and provider are identical, determines the processes of resource management and the lower technical efficiency. On the one hand, cooperatives put people, not capital, in the core of the business, meaning that the decisions made by cooperatives are meant to balance the profitability objects and the interests of their members and sometimes even of the community where they are located in (Soboh et al. 2009). On the other hand, there is no doubt that the extra services that many of these entities provide (capital financing, accounting management, etc.) could be regarded as another output or, at least, as a positive externality of the production process in future research.

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