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Assessing technical efficiency in traditional olive grove systems: A directional metadistance function approach

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ABSTRACT: Olive growing is the main agricultural activity in Andalusia, although the systems used are far from homogenous. Indeed, technological and natural characteristics have led to the implementation of several growing systems. Our goal is to analyze the efficiency of the two most important systems in Andalusia: traditional rain-fed mountain and plain olive groves. In this paper we not only assess the efficiency of olive farms but also assess the efficiency of farming systems. Additionally, this analysis takes into account the traditional radial input orientation and also the input-specific efficiency. The results highlight the advantages of the plain olive grove system in front of the mountain olive grove system.

KEYWORDS: Data Envelopment Analysis, directional distance functions, metafrontier, olive farming, technical efficiency.

JEL classification: C61, L23, Q12, Q18.

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Valoración de la eficiencia técnica en los sistemas de olivar tradicional: Una aproximación con funciones metadistancia direccionales

RESUMEN: El olivar es la principal actividad agraria en Andalucía, si bien este no es un cultivo homogéneo. En función de las características naturales y tecnológicas se han desarrollado diversos sistemas de olivar. Nuestro objetivo es analizar la eficiencia de los dos sistemas más importantes en Andalucía: el cultivo tradicional de secano en montaña y en campiña. Más allá de valorar la eficiencia de las explotaciones olivareras valoramos también la eficiencia de los sistemas de cultivo, considerando no solo la orientación en input tradicional sino además la eficiencia en inputs específicos. Los resultados ponen de relieve las ventajas del olivar de campiña frente al de montaña.

PALABRAS CLAVE: Análisis envolvente de datos (DEA), funciones distancia direccionales, metafrontera, cultivo del olivar, eficiencia técnica.

Clasificación JEL: C61, L23, Q12, Q18.

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1. Introduction

Olive farming has been a feature of the Mediterranean economy since ancient times. Tradition and culture add to the importance of olive growing as an emblematic agro-system with high environmental and landscape value, without neglecting its social and economic significance. Olive growing is a driving force behind the generation of income, wealth and employment, which makes it easier for people to settle in rural areas (Loumou and Giourga, 2003). As such, it is a clear example of multifunctional farming.

Andalusia is the largest olive-growing region in the world. With an area of 1.4 million hectares, it accounts for approximately a third of the area used for olive growing in the European Union and two thirds of the total area used in Spain. This production is used almost entirely to obtain virgin olive oil, of which Andalusia, with 1.2 million tons, is the largest producer and exporter in the world. In this region, 31% of agricultural land is devoted to olive groves, the output of which represents about a quarter of agricultural production and generates one third of the employment in this sector. In addition, it is the main economic activity in more than 300 Andalusian municipalities (CAP, 2008).

However, olive groves are far from homogeneous. Several different types of olive growing or farming systems can be distinguished, their edapho-climatic and technological characteristics resulting in significant differences in both economic and environmental performance. Although the implementation of Common Agricultural Policy (CAP)[1] led to the intensification of this crop and the emergence of highly intensive farms in more fertile grounds previously used for other crops (Gallardo *et al.,* 2002), traditional rain-fed olive groves remain predominant in Andalusia (Gómez-Limón and Arriaza, 2011).

Several studies have analysed the impact of agricultural policies on the viability of olive groves and environmental issues such as biodiversity and soil erosion. Some highlight the importance of maintaining mountain olive groves (Duarte *et al.,* 2008) and reducing the environmental problems caused by certain farming practices (Graaff and Eppink, 1999; Beaufoy and Pienkowski, 2000; Graaff *et al.,* 2010)[2], while others highlight the need to support measures not based on productivity and to demand some form of conditionality on behalf of more intensive olive growing systems. Alternatively, when the goal is to avoid the abandonment of mountain olive groves or to foster the implementation of organic farming, agri-environmental schemes could be the solution (Fleskens and Graaff, 2010; Graaff *et al.,* 2011; Parra-López *et al.,* 2008; Xiloyannis *et al.,* 2008).

[1] While promoting the Mediterranean diet and the consumption of olive oil has a positive impact on olive grove production, it is production subsidies that most affect their growth (Scheidel and Krausmann, 2011).

[2] Calatrava *et al.* (2007), Franco and Calatrava (2010; 2012) the factors influencing the adoption of soil conservation farming practices in olive groves as a way to control erosion problems, particularly no-till and herbicide treatment.

Because of the multifunctional nature of agriculture in general and olive growing in particular[3], the quality of olive grove systems has been analysed considering a range of criteria, not only economic viability, and analysis techniques (Amores and Contreras, 2009; Elfkih *et al.,* 2012; Gómez-Limón and Arriaza, 2011; Graaff *et al.,* 2011; Guzmán and Alonso, 2008; Parra *et al.,* 2005; Xiloyannis *et al.,* 2008)[4]. In particular, recent studies use Data Envelopment Analysis (DEA) techniques to simultaneously measure the economic and ecological efficiency, or eco-efficiency, of both individual farms and the main olive growing systems (Beltrán-Esteve *et al.,* 2013; Gómez-Limón *et al.,* 2012; Picazo-Tadeo *et al.,* 2012). These studies find that there is a strong relationship between the eco-inefficiency and technical inefficiency of olive farms. Furthermore, they show that it is possible to improve economic and environmental performance simultaneously. In fact, in the presence of technical inefficiency, farmers can reduce the amount of inputs used without adopting new technologies or farming practices and without reducing production. Thus, farms can improve their economic performance while also reducing their negative impact on the environment, given the close relationship between the use of some inputs and environmental spillovers. Analysing technical efficiency is therefore an essential part of assessing olive grove systems.

In this line of research, some studies have employed frontier techniques to assess technical efficiency in olive orchards. In general, all olive groves are assumed to share the same production technology or, when technological heterogeneity is recognised, the efficiency of each farm is assessed in regard to the technology of the system it belongs to. In particular, Tzouvelekas *et al.* (2001) and Karagiannis and Tzouvelekas (2009a; 2009b) applied stochastic models to estimate the technical efficiency of olive groves in Greece, while Lambarraa *et al.* (2007) did the same for Spanish olive groves. All of these studies analyse individual farm performance in regard to the efficient frontier of the olive grove system without assessing the relative efficiency of the olive growing systems themselves. Moreover, Amores and Contreras (2009) use DEA techniques to analyse the efficiency of Spanish olive orchards taking into account the presence of different types of olive grove.

The aim of this paper is to analyse the differences in efficiency between the two major olive grove systems in Andalusia, which together account for two thirds of the area devoted to olive groves in the region. Using the methodological approach developed in Sáez-Fernández *et al.* (2012), this research assesses both the efficiency of each farm relative to the technological frontier of the olive growing system it belongs to, and the efficiency of each olive growing system as a whole in regard to the so-called metafrontier, that represents a sort of joint technology. Furthermore, we construct several input-specific efficiency indicators using directional distance functions and an indicator of efficiency that considers all the inputs used by producers as a whole.

3 Kallas *et al.* (2006) and Arriaza *et al.* (2008) estimate the demand for social and environmental functions of Andalusian mountain olive groves. The most valued attributes were maintaining the rural population and erosion control.

4 Dios-Palomares and Martínez-Paz (2011) analyse the technical and environmental efficiency of the Andalusian olive oil industry.

Input-specific indicators allow us to assess differences in technical efficiency between growing systems as regards the management of particular production factors.

Regarding the organisation of the paper, the next section discusses Andalusian olive growing systems and describes their production processes using the sample data. Section 3 outlines the methodology, while Section 4 presents and discusses the results obtained. Finally, Section 5 concludes and raises potential policy implications.

2. Sector under study and sample

Olive trees are, as already noted, the most widespread crop in Andalusia, but growing systems are far from homogeneous. Edaphoclimatic and technological characteristics make it possible to establish a typology of cultures on the basis of which to classify farms. The structural variables commonly used are the age of the plantation, cultivation system (rain-fed, irrigated), planting density and the number of feet per tree (traditional, intensive), the slope of the terrain (mountains, plains) and the fate of production (mill, table). According to these features, more than thirty types of olive groves can be distinguished. However, this paper focuses on the two most important mill olive growing systems in Andalusia[5] (Gómez-Limón and Arriaza, 2011), namely:

- *Traditional mountain groves* (33% of the surface area): rain-fed cultivation with large planting frames and steep slopes. Although some tasks have been mechanised and the use of agrochemicals has increased, this system is still characterised by very low levels of profitability and significant positive environmental externalities.
- *Traditional plain groves* (32% of the surface area): rain-fed cultivation with large planting frames on moderately steep terrain and good agronomic characteristics. In recent years the productivity of this system has improved through mechanisation and the use of agrochemicals (fertilisers and pesticides).

The data used in this article come from a survey carried out on a sample of farms in the region as part of a larger study aimed at analysing the sustainability of Andalusian olive groves[6]. As we are interested in defining groups of farms with suitably homogenous technological and natural conditions, we only use data from traditional rain-fed mountain and plain olive groves[7] located in the central Andalusian provinces

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[5] Mill olive orchards are predominant in the region, accounting for around 95% of total acreage.

[6] The survey was conducted by interviewers between May and September 2010. For details on the sampling and analysis coverage, see Gómez-Limón and Arriaza (2011).

[7] The main differences between the two olive growing systems are due to the slope of plantations. The suitable cultivation techniques are different depending on the slope. In particular, the mountain system presents important problems to use machinery such as the trunk vibrator; instead, branch vibrators which require more labour need to be used (CAP, 2002).

of Cordoba and Jaen[8]. After removing outliers, the sample used in this paper contains 99 mountain groves and 121 plain groves.

In order to analyse the technical efficiency of olive grove systems, information has been compiled regarding the output, the surface area, which is considered a fixed input, and the main variable inputs used by each sample farm. More specifically, the output of the production process is measured as the volume of olives in kilograms (*olives*). As regards the inputs, olive grove surface area is measured in hectares (*land*), the cost of the machinery used, which includes depreciation, maintenance and repair, is measured in euros (*machinery*), the labour employed in the various tasks associated with growing olive trees, both family and hired, is measured in days (*labour*), while the costs associated with the purchase of pesticides, fungicides or herbicides (*pesticides*), chemical and organic fertilisers (*fertilisers*) and energy use (*energy*) are measured in euros.

Table 1 provides information on land productivity and how intensively both mountain and plain olive grove systems use each input. The table shows how plain olive grove land productivity is higher and that this system uses machinery, pesticides and energy more intensively than mountain olive groves, differences being statistically significant. By contrast, there are no statistically significant differences in how intensively the two growing systems use labour and fertilisers. In summary, there are differences between plain and mountain olive growing technologies: A more intensive use of inputs in plain olive groves results in higher production per hectare or land productivity.

Table 2 presents the main descriptive statistics for the variables used in our efficiency analysis. More importantly, this analysis does not include expenditure on fertilisers and energy. In the first case, this choice is justified by the fact that olive trees have multiannual fertilisation patterns, whereas the information obtained in the survey refers to annual fertilisation. This would lead us to consider a farm that has fertilised during the year of the survey as inefficient when compared to a similar farm that fertilised the previous year. In the second case, the exclusion of energy expenditure is justified as this input is very closely related to machinery and, therefore, does not yield significant additional information[9]. In a preliminary analysis of the data, it is worth highlighting that there are no statistically significant differences between the olive growing systems examined as far as farm size is concerned, or in the use of labour. On the contrary, statistically significant differences do emerge between olive mountain groves and plain groves as regards the production obtained by olive farms and the expenditure incurred in both machinery and pesticides.

8 More specifically, mountain farms in the region of *La Sierra* are not included in this study because their soil and climate conditions are very different from those faced by mountain farms in the central counties of *Penibética* and *Sierra Sur*. In fact, mountain olive groves in these regions record relatively high levels of productivity.

9 The correlation coefficient between the two variables is 0.994.

TABLE 1

Land productivity and input use intensity

	Unit	Mean	Standard deviation	Maximum	Minimum
Traditional mountain groves					
Production	Kg h^{-1}	3,977.3	1,098.7	7,000.0	2,000.0
Labour	Days h^{-1}	6.0	1.0	9.6	2.9
Machinery	Euros h^{-1}	44.0	17.4	103.4	17.7
Energy	Euros h^{-1}	72.6	31.5	176.0	21.2
Pesticides	Euros h^{-1}	56.6	34.2	282.2	15.7
Fertilisers	Euros h^{-1}	104.7	74.0	334.8	1.2
Traditional plain groves					
Production	Kg h^{-1}	4,515.7	1,712.4	8,000.0	1,500.0
Labour	Days h^{-1}	5.8	1.2	8.6	3.2
Machinery	Euros h^{-1}	67.1	23.8	114.5	17.7
Energy	Euros h^{-1}	113.4	43.6	199.2	21.2
Pesticides	Euros h^{-1}	73.3	55.1	478.0	10.9
Fertilisers	Euros h^{-1}	92.1	89.7	624.5	0.0

Source: Own elaboration.

TABLE 2

Sample descriptive statistics

	Unit	Mean	Standard deviation	Maximum	Minimum
Traditional mountain groves					
Production	Kilograms	51,188.4	75,109.5	585,000.0	2,000.0
Land	Hectares	12.5	17.3	130.0	1.0
Labour	Days	73.2	105.4	854.3	4.6
Machinery	Euros	590.8	871.1	5,577.9	17.7
Pesticides	Euros	767.9	1,279.6	8,324.4	18.0
Traditional plain groves					
Production	Kilograms	76,093.4	107,100.9	700,000.0	2,250.0
Land	Hectares	17.2	23.1	175.0	1.0
Labour	Days	94.1	117.2	800.0	5.4
Machinery	Euros	1,100.0	1,369.5	7,218.0	44.9
Pesticides	Euros	1,528.5	3,875.0	38,236.8	28.8

Source: Own elaboration.

In this context, it is relevant to consider whether the observed differences in land productivity and input intensities between both systems are due to differences in the efficiency of the farms or the conditions and limitations of the technology used by the olive growing systems themselves. Moreover, the analysis of input-specific technical efficiency will provide more accurate knowledge regarding the possibilities of improving each system and also better guidance for the implementation of agricultural policy measures.

3. Methodology

In order to present the main insights of the methodological approach used in this study, by adapting Sáez-Fernández *et al.* (2012) we assume that we observe a set of k=1, …, K olive growers, who use a fixed input and a set of three variable inputs in their production process to produce one output. The output, *olives*, is denoted by y, while the set of inputs is denoted by the vector $\mathbf{x} = (\mathbf{x}_f, \mathbf{x}_v)$, $\mathbf{x}_f$ being the fixed input, *land,* and $\mathbf{x}_v$ the variable inputs, including *machinery, labour* and *pesticides*. Both the output and inputs are assumed to be non-negative.

3.1. Metatechnology

The metatechnology can be represented by the *short-term input requirement metaset*, namely $L(y,\mathbf{x}_f)$, representing all combinations of variable inputs that, given an endowment of fixed factors, can produce, at least, the output y (Picazo-Tadeo and Reig-Martínez, 2006):

$$L(y, \mathbf{x}_f) = \langle \mathbf{x}_v | (\mathbf{x}, y) \in T \rangle \quad [1]$$

where T represents all the feasible combinations of inputs and output given the present state of the technology.

Directional metadistance functions, $\overrightarrow{\mathrm{MD}}$ (Chambers *et al.*, 1998), provide another representation of the metatechnology[10]:

$$\overrightarrow{\mathrm{MD}}\left[\mathbf{x}, y; \mathbf{g} = \left(-\mathbf{g}_{\mathbf{x}_v}, g_y\right)\right] = \mathrm{Sup}\langle \beta | \left(\mathbf{x}_v - \beta \mathbf{g}_{\mathbf{x}_v}\right) \in L\left[\left(y + \beta g_y\right), \mathbf{x}_f\right] \rangle \quad [2]$$

$\mathbf{g} = (-\mathbf{g}_x, g_y)$ being the direction vector.

[10] Färe and Grosskopf (2000) summarise the theory of directional distance functions.

The directional metadistance function in expression [2] is always equal to or greater than zero (Chambers *et al.,* 1998) and models inputs and output jointly, allowing for an increase in output and a simultaneous reduction in inputs through a path represented by direction vector **g**. Therefore, the directional metadistance function is looking for the maximum feasible increase in output following direction g_y and cutting down on inputs in direction $-\mathbf{g}_x$ while remaining within the metatechnology set. One important feature of directional distance functions is that they provide a very flexible tool for efficiency analysis (Picazo-Tadeo *et al.*, 2012). In this sense, different direction vectors make it possible to approach the technological frontier via alternative paths, allowing us to focus the analysis on different facets of production process relationships.

More specifically, if we are interested in assessing the maximum proportional saving of all variable inputs consistent with the metatechnology, given a fixed factor endowment and maintaining production levels, the direction vector that models this would be $\mathbf{g}_{\text{all}} = (-\mathbf{x}_{\mathbf{v}}, 0)$, and the directional metadistance function:

$$\overrightarrow{\text{MD}}_{\text{all}}\,[\mathbf{x}, y; \mathbf{g}_{\text{all}} = (-\mathbf{x}_{\mathbf{v}}, 0)] = \text{Sup}[\beta_{\text{all}}\,|(1-\beta_{\text{all}})\mathbf{x}_{\mathbf{v}} \in L(y, \mathbf{x}_{\mathbf{f}})] \qquad [3]$$

A score of zero for this function denotes efficiency, i.e., a proportional reduction in inputs is not possible without a decrease in output. Furthermore, a higher β_{all} value indicates a higher potential saving in inputs and therefore a lower level of efficiency.

Alternatively, we can assess performance for a specific input or group of inputs. In doing so, if our interest is to obtain the maximum feasible saving of a variable input or group of variable inputs i, while maintaining the other inputs, –i, and the output at their observed levels, the direction vector for the input-specific efficiency scores would be $\mathbf{g}_{\text{i}} = [(-\mathbf{x}_{\mathbf{vi}}, \mathbf{0}_{-\mathbf{i}}), 0]$, and the directional metadistance function:

$$\overrightarrow{\text{MD}}_{\text{i}}\,\langle\mathbf{x}, y; \mathbf{g}_{\text{i}} = [(-\mathbf{x}_{\mathbf{vi}}, \mathbf{0}_{-\mathbf{i}}), 0]\rangle = \text{Sup}\langle\beta_{\text{i}}|[(1-\beta_{\text{i}})\mathbf{x}_{\mathbf{vi}}, \mathbf{x}_{\mathbf{v-i}}] \in L(y, \mathbf{x}_{\mathbf{f}})\rangle \qquad [4]$$

The efficiency score for a specific input or group of inputs, β_i in expression [4], will be equal to or greater than the score obtained when reducing all the inputs proportionally, β_{all} in expression [3].

In order to make these indicators easier to understand, let us take a traditional mountain olive grove *k'* and the input *pesticides* as an example. If the directional metadistance score for this farm in expression [3] is 0.3, it could reduce its use of pesticides and all other inputs by 30% while maintaining olive production. If the *pesticide*-specific score in expression [4] is 0.35, this farm could reduce the amount of pesticides used by 35% without increasing the use of the other inputs and holding output constant. It is worth noting that in this case, the *pesticide*-specific score will never be lower than 0.3; i.e., if it is possible to reduce the use of pesticides and all other inputs simultaneously by 30%, it should be possible to reduce the use of pesticides alone by at least 30%.

3.2. Group technology

Taking into account the natural and technological heterogeneity of olive farms entails defining specific technology sets for each olive growing system, i.e., *group frontiers*. The farms in the sample fall into two groups, traditional mountain groves and traditional plain groves, such that the constraints imposed by the production environment prevent producers in one group from accessing the full range of input-output combinations in the metatechnology set.

Group technology is assumed to share the same properties as the metatechnology, including convexity. Moreover, the *short-term input requirement set* for group h, namely $L^h(y, \mathbf{x_f})$, is defined as:

$$L^h(y, \mathbf{x_f}) = \langle \mathbf{x_v} | (\mathbf{x}, y) \in T^h \rangle \quad [5]$$

where T^h(h = *mountain, plain*) is the *technology set* for group h representing all the input-output combinations available to farms in this group.

The directional distance functions that allow us to evaluate efficiency in regard to the technology of group h, when all variable inputs are proportionally reduced and only one specific variable input or group of inputs i is reduced are, respectively:

$$\vec{\mathrm{D}}^{\mathrm{h}}_{\mathrm{all}}[\mathbf{x}, y; \mathbf{g}_{\mathrm{all}} = (-\mathbf{x_v}, 0)] = Sup[\, \beta^{\mathrm{h}}_{\mathrm{all}} | (1 - \beta^{\mathrm{h}}_{\mathrm{all}})\mathbf{x_v} \in L^h(y, \mathbf{x_f})] \quad [6]$$

$$\vec{\mathrm{D}}^{\mathrm{h}}_{\mathrm{i}}\langle \mathbf{x}, y; \mathbf{g}_{\mathrm{i}} = [(-\mathbf{x_{vi}}, \mathbf{0_{-i}}), 0]\rangle = \mathrm{Sup}\langle \beta^{\mathrm{h}}_{\mathrm{i}} | [(1 - \beta^{\mathrm{h}}_{\mathrm{i}})\mathbf{x_{vi}}, \mathbf{x_{v-i}}] \in L^h(y, \mathbf{x_f})\rangle \quad [7]$$

Group directional distance functions will always be equal to or lower than the directional metadistance function, which is a way of saying that the metatechnology envelops the group technologies.

Coming back to our example of farm *k'*, where the directional metadistance function for *pesticides* in expression [4] takes a value of 0.35, let us now assume the directional distance function for *pesticides* in expression [7] is 0.2. This means that if there were no restrictions on technology or the natural environment, farm *k'* could reduce its use of pesticides by 35% and produce the same amount of olives without increasing the use of the remaining inputs. Notwithstanding, when we take into account the restrictions affecting traditional mountain farms, i.e., expression [7], pesticide use by farm *k'* could be reduced by only 20% if output and all other inputs remain constant. The differences between the two scores can be attributed to the inherent disadvantages of the olive system that farm *k'* belongs to. *Metatechnology ratios* capture these disadvantages by assessing how close the technology of group h is to the metatechnology.

3.3. Metatechnology ratio

In order to compute metatechnology ratios it is nevertheless convenient to express technical efficiency in a more conventional way as do Sáez-Fernández *et al*. (2012).

The *metatechnology ratio* for group h when considering a direction that proportionally reduces all the variable inputs is formalized as:

$$\text{Metatechnology ratio}^{\text{h}}_{\text{all}}[\mathbf{x}, y; \mathbf{g}_{\text{all}} = (-\mathbf{x_v}, 0)] = \frac{\text{Metaefficiency}_{\text{all}}}{\text{Efficiency}^{\text{h}}_{\text{all}}} = \frac{(1 - \beta_{\text{all}})}{\left(1 - \beta^{\text{h}}_{\text{all}}\right)} \quad [8]$$

Both, technical efficiency and metaefficiency are upper-bounded to one, this score indicating efficient performance. Furthermore, the efficiency score is always equal to or greater than the metaefficiency score because group h has restricted access to the available technology. A metadistance function farm *k'* value of 0.3, as we have seen, indicates that farm *k'* can reduce all its inputs proportionally by 30% without reducing its output. Alternatively, we can say that, with unrestricted access to the available technology and efficient performance, farm *k'* could produce the same amount of olives using only 70% of the inputs actually used. This is just what metaefficiency shows us. The same interpretation applies to efficiency scores.

The metatechnology ratio assesses how close the technological frontier of group h is to the unrestricted technological frontier or metafrontier, measured in this case using a direction that proportionally reduces all the inputs while maintaining the production level. Farm *k'* used in our example, with metaefficiency of 0.7 and efficiency of 0.8, will yield a metatechnology ratio of 0.875. This means that efficient inputs with respect to the non-restricted technology are only 87.5% of the efficient inputs when using the restricted technology of the group h. In other words, natural and technical restrictions for group h impose a 12.5 % input excess.

This approach provides a useful breakdown of an efficiency indicator measured in regard to the metafrontier representing the state of knowledge, referred to as metaefficiency, into the product of a measure of efficiency with respect to the technological frontier of group h, referred to as efficiency^{h}, and the metatechnology ratio for group h (O'Donnell *et al.,* 2008: 237). The relationship could be formalised as:

$$\text{Metaefficiency}_{all} = \text{Efficiency}^{\text{h}}_{\text{all}} * \text{Metatechnology ratio}^{\text{h}}_{\text{all}} \quad [9]$$

Alternatively, we can assess the performance in the management of a specific input or group of inputs i, in terms of efficiency, both relative to the metafrontier and to the group h frontier in very similar fashion, and define the group h input-specific metatechnology ratio for the input or group of inputs i, as:

$$\text{Metatechnology ratio}^{\text{h}}_{\text{i}}\langle \mathbf{x}, y; \mathbf{g}_{\text{i}} = [(-\mathbf{x}_{\mathbf{vi}}, \mathbf{0}_{-\mathbf{i}}), 0]\rangle = \frac{\text{Metaefficiency}_{\text{i}}}{\text{Efficiency}^{\text{h}}_{\text{i}}} = \frac{(1 - \beta_{\text{i}})}{\left(1 - \beta^{\text{h}}_{\text{i}}\right)} \quad [10]$$

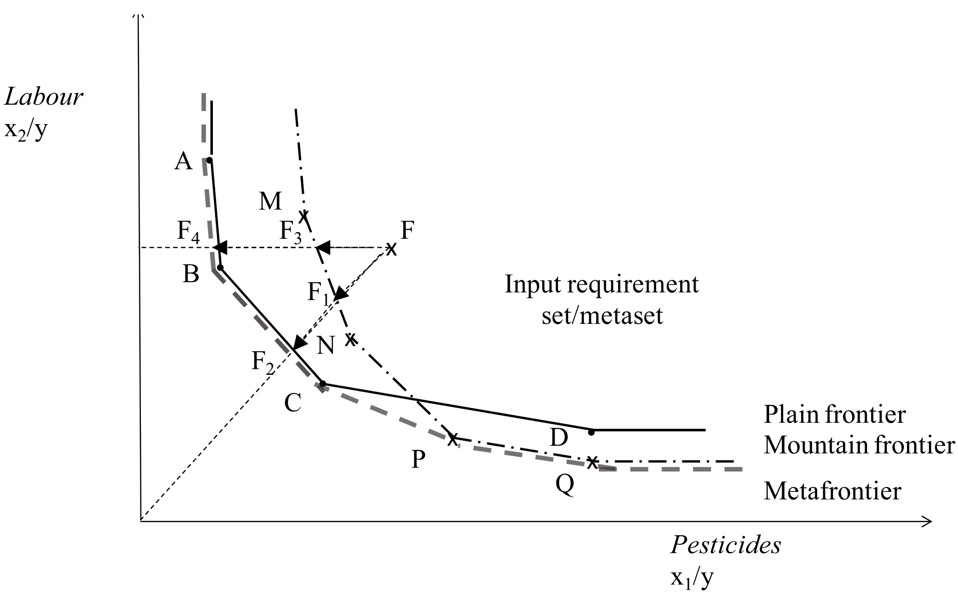
Input-specific metatechnology ratios assess how close the group h frontier is to the metafrontier when attending to a specific input i. The decomposition in expression [9] also applies here.

3.4. A graphical illustration

Both the metafrontier approach and the meaning of the metatechnology ratio can be expressed in graph form (Graph 1). For the sake of simplicity, we assume a technology in which the production of output *y*, *olives*, requires only two inputs, namely x_1 (*pesticides*) and x_2 (*labour*). Furthermore, we assume that we observe a set of farms belonging to the traditional plain olive grove (A, B, C and D represented by dots) and traditional mountain olive grove (F, M, N, P and Q represented by crosses) systems. Under the assumptions made regarding the technology, the technological frontier for traditional plain groves is shaped by the efficient farms included in this group, A to D, and their convex combinations, while for the mountain groves the efficient farms shaping the frontier are M to Q. The metafrontier is the convex combination of the mountain and plain frontiers and is shaped by the metaefficient farms belonging to the plain grove system (A, B, C) and the ones belonging to the mountain grove system (P, Q).

GRAPH 1

Metafrontier approach and metatechnology ratios



Source: Own elaboration.

The production plan of the mountain grove farm F is located in an inner point of the input requirement set, so it is technically inefficient, i.e., inputs used are greater than strictly necessary to obtain output *y*, both in terms of the metatechnology and the mountain grove technology. Projecting farm F onto the mountain frontier in a direction that proportionally reduces pesticides and labour yields F_1, showing the minimum use of pesticides and labour required to obtain the olive production *y* efficiently using its own technology. However, if farm F had unrestricted access to the available technology, it could reduce its inputs up to F_2, which is the projection onto the metafrontier. The metatechnology ratio from expression [8] would measure the technological gap between the mountain frontier and the metafrontier. Moving on, assessing efficiency in a direction in which the input *pesticides* is reduced without increasing the use of labour and holding the level of production constant, projecting farm F onto the mountain frontier results in F_3, while efficient inputs with respect to the unrestricted technology will be F_4. The metatechnology ratio would measure the technology gap as regards the management of pesticides.

3.5. Computing directional distance and metadistance functions

Various methodological approaches can be taken to address the calculation of directional metadistance and distance functions. Essentially, all of them rely on the calculating an efficient frontier that represents the best possible practices given a state of knowledge or technology. The technological frontier can be calculated using either parametric or non-parametric techniques. Our choice is to use Data Envelopment Analysis (DEA) techniques, a non-parametric approach to efficiency measurement pioneered by Charnes *et al.* (1978). DEA has several advantages over the parametric approach to efficiency measurement. One of the most noticeable is that no prior assumptions regarding the specific functional form of the technology are required. DEA constructs a piecewise linear technological frontier representing best practices on the basis of empirical observations and some basic properties regarding the technology (Cooper *et al.*, 2007 for an appraisal of the foundations of DEA).

Accordingly, the DEA program required to calculate the directional metadistance function in expression [3] for a farm *k'* allowing for a proportional reduction of all variable inputs, namely, *pesticides, machinery* and *labour*, while holding constant fixed input, $\mathbf{x}_f$, and output, *y*, is:

$$\underset{\beta_{all}^{k'},z^k}{\text{maximise}}\ \beta_{all}^{k'} \qquad k' \in k = 1, \dots, K \qquad [11]$$

subject to:

$$y^{k'} \leq \sum_{k=1}^{K} z^k y^k \qquad \text{(i)}$$

$$x_f^{k'} \geq \sum_{k=1}^{K} z^k x_f^k \qquad \text{(ii)}$$

$$(1-\beta_{all}^{k'})x_{vi}^{k'} \geq \sum_{k=1}^{K} z^k x_{vi}^k \qquad i=1,2,3 \qquad \text{(iii)}$$

$$z^k \geq 0 \qquad k=1,...,K \qquad \text{(iv)}$$

Furthermore, the DEA program that calculates the specific directional metadistance function for a farm *k'* allowing for a reduction of *pesticides,* x_1, while the other variable inputs, land and output are held constant is:

$$\underset{\beta_i^{k'}, z^k}{\text{maximise}}\ \beta_i^{k'} \qquad k' \in k = 1, \ldots, K \quad \text{and} \quad i = pesticides \qquad [12]$$

subject to:

$$y^{k'} \leq \sum_{k=1}^{K} z^k y^k \qquad \text{(i)}$$

$$x_f^{k'} \geq \sum_{k=1}^{K} z^k x_f^k \qquad \text{(ii)}$$

$$(1-\beta_i^{k'})x_{vi}^{k'} \geq \sum_{k=1}^{K} z^k x_{vi}^k \qquad i = 1 \qquad \text{(iii)}$$

$$x_{v-i}^{k'} \geq \sum_{k=1}^{K} z^k x_{v-i}^k \qquad -i = 2,3 \qquad \text{(iv)}$$

$$z^k \geq 0 \qquad k = 1,...,K \qquad \text{(v)}$$

Adequate substitution of variable inputs into constraints (iii) and (iv) results in the programs for calculating the specific directional metadistance functions measured in the direction of a reduction in *machinery* and that of a reduction in *labour*, respectively; always holding all other variable inputs, land and output constant. These are the programs valuing expression [4].

In all these programs, variable z^k represents the weighting of each farm k in the construction of the metafrontier that farm *k'* is compared to; when z^k is positive, farm k is said to be a *peer* for *k'*. By allowing the sum of these weights to be free, we are assuming constant-returns-to-scale technology[11]. Only a few changes in notation and the substitution of the entire sample with the observations in the sample of group h farms are required to calculate group h distance and metadistance functions, which is left to readers.

[11] Our objetive is to measure total technical efficiency, regardless of the production scale. Furthermore, the non-radial nature of some of our measures of efficiency, i.e. those that reduce only one input, could pose some problems in measuring returns to scale, as returns to scale are basically a radial concept (Krivonozhko *et al.,* 2012; Torgersen *et al.,* 1996).

4. Results

Using the dataset and variables described in Section 2 and the methodology developed in Section 3, we have calculated directional metadistance functions and directional distance functions for each farm in the sample. Metadistance functions in regard to the metatechnology (expression 3) for each farm *k'* in a direction that reduces all variable inputs are calculated by solving program [11]. Moreover, this program has been used to obtain the radial distance functions for each farm *k'* in regard to their own group frontier from expression [6]. Then metaefficiency and efficiency scores have been calculated as well as metatechnology ratios according to expression [8]. Table 3 presents some descriptive statistics of these results for the plain and mountain olive grove systems.

Furthermore, program [12] and its variants are used to obtain three input-specific metadistance functions (i.e. *pesticides, machinery* and *labour*) in regard to the metafrontier, and the corresponding input-specific directional distance functions in regard to the technological frontier of the olive grove system they belong to (expressions 4 and 7, respectively). Then, expression [10] has been used to calculate the input-specific metaefficiency scores, input-specific efficiency scores and the metatechnology ratio for each farm *k'*. Descriptive statistics for both mountain and also plain olive grove systems are shown in Table 4.

Regarding the results reported in Table 3 on radial technical efficiency, the high degree of inefficiency in traditional rain-fed olive groves in Andalusia is remarkable[12]. In the first place, we take into account farms' technical efficiency scores in regard to their own group technology in a direction that proportionally reduces the use of pesticides, machinery and labour, while holding farm output constant. When comparing mountain olive farms to the best practices of their own group, on average they could reduce their use of inputs by up to 65% of their actual level; i.e. their technical efficiency score is 0.651. This is the same as saying that efficient management of mountain farms would yield a saving of close to 35% in the use of labour, machinery and pesticides while maintaining production levels. In the case of plain farms, potential savings amount to 46% of the inputs actually used, showing even lower levels of technical efficiency regarding their own technology than mountain farms. Notwithstanding, it is necessary to emphasise that mountain technical efficiency scores and plain technical efficiency scores are in no way directly comparable, because they are computed in regard to different benchmark technologies. Therefore, when we talk about the greater technical efficiency of mountain olive farms, all that is being said is that mountain

[12] High technical inefficiencies are quite frequent in the case of farms, especially for rain-fed crops (Barreiro-Hurlé *et al.,* 2009; Larsén, 2010; Latruffe *et al.*, 2005, 2012; Reig-Martínez and Picazo-Tadeo, 2004). For Greek conventional olive groves, Tzouvelekas *et al.* (2001) estimates input-oriented technical efficiency, which on average, stands at 0.543; i.e. all inputs could be proportionally reduced by 46% without reducing olive production. Karagiannis and Tzouvelekas (2009b: 69) report mean technical efficiency scores for various parametric models in the Greek case showing in general high inefficiencies, although there are important differences in regard to the functional form assumed. Lambarraa *et al.* (2007) and Amores and Contreras (2009) also find high technical inefficiencies for Spanish olive groves.

farms are closer to their own frontier than plain farms to their own frontier, without saying anything about the relative position of these technological frontiers.

TABLE 3

Estimates of radial technical efficiency

	Mean	Standard deviation	Maximum	Minimum
Technical efficiency with respect to the metafrontier ($1\text{-}\beta_{all}$)				
Traditional mountain groves	0.582	0.182	1	0.233
Traditional plain groves	0.534	0.220	1	0.188
Technical efficiency with respect to the group frontier ($1\text{-}\beta^{h}_{all}$)				
Traditional mountain groves	0.651	0.184	1	0.288
Traditional plain groves	0.542	0.224	1	0.193
Metatechnology ratio ($1\text{-}\beta_{all}$)/($1\text{-}\beta^{h}_{all}$)				
Traditional mountain groves	0.890	0.095	1	0.591
Traditional plain groves	0.985	0.025	1	0.840

Source: Own elaboration.

Nonetheless, the metatechnology ratio measures how close the group frontier is to the metafrontier. The plain olive grove frontier is very close to the metafrontier, with a ratio of 0.985. On the contrary, the radial metatechnology ratio of traditional mountain groves is much lower, reflecting significant natural and technological restrictions. More specifically, an average value of 0.89 for this ratio indicates that an efficient use of inputs in mountain technology represents an overuse of inputs of 11% in relation to the metafrontier.

In summary, the mountain olive grove system faces a greater disadvantage in relation to unrestricted technology than plain olive groves. However, mountain farmers are, in reference to their own technology, relatively more efficient than their plain counterparts, compensating in this manner for their technological disadvantage.

It is important to assess whether or not the differences in efficiency between the two olive grove systems are statistically significant. In order to do so we have performed several non-parametric tests, namely the *Kolmogorov–Smirnov* test, the *Mann–Whitney rank sum* test and the *Simar-Zelenyuk-adapted-Li* test. The results, reported in Table 5, show that differences in metatechnology ratios between the two olive grove systems are statistically significant when considering a proportional reduction in all variable inputs. Furthermore, the Kernel density estimation functions of the metatechnology ratio for both plain and mountain olive systems are displayed in Graph 2.

Are radial results equally valid for all inputs? Are there any differences in the efficiency with which the various inputs are used in each olive grove system? What can we say about closeness of the group frontiers to the metafrontier when measured in a specific input direction? Table 4 shows the results for the efficiency indicators measured in the direction of each specific input. In regard to input-specific technical efficiency in regard to own group technology, it is noteworthy that in both systems the largest technical inefficiencies occur in the use of pesticides. On average, plain farms could reduce their current use of pesticides by up to 32.5% while mountain farms could do so by up to 39.4%. In contrast, labour is the input used most efficiently by farmers in both systems; notwithstanding, it is largely inefficient too[13]. Furthermore, for each of the inputs that we consider, mountain farmers are more efficient producers than plain farmers in regard to their respective technologies.

TABLE 4

Estimates of input-specific technical efficiency

	Labour		Machinery		Pesticides	
	Mean	**Standard deviation**	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**
Technical efficiency with respect to the metafrontier ($1-\beta_i$)						
Traditional mountain groves	0.370	0.176	0.392	0.215	0.320	0.215
Traditional plain groves	0.425	0.227	0.333	0.261	0.311	0.250
Technical efficiency with respect to the group frontier ($1-\beta_i^h$)						
Traditional mountain groves	0.485	0.230	0.443	0.234	0.394	0.255
Traditional plain groves	0.432	0.238	0.350	0.270	0.325	0.265
Metatechnology ratio ($1-\beta_i$)/($1-\beta_i^h$)						
Traditional mountain groves	0.781	0.098	0.882	0.083	0.824	0.130
Traditional plain groves	0.993	0.046	0.957	0.075	0.973	0.073

Source: Own elaboration.

Regarding the group frontier location relative to the metafrontier, input-specific metatechnology ratios show that there are important and statistically significant differences between the two technologies for each direction considered. The plain olive grove frontier is very close to the metafrontier for each specific input direction, particularly for labour, with a ratio of 0.993. The major constraints faced by this system, albeit not very large, relate to the use of machinery. However, technological and natural constraints are much more significant for mountain olive groves. In regard to the use of labour, if there were no limits on access to the metatechnology, potential savings could amount to nearly 22%; although not as large, the savings in machinery could reach 12%, being the input that performs the best for mountain technology. In short, technology and environmental conditions are more favourable in the case of plain olive farms than mountain farms. This is true for the use of machinery and pesticides and especially the use of labour.

[13] Karagiannis and Tzouvelekas (2009a) also report significant differences in the scores of single factor technical efficiency estimates for Greek olive groves.

TABLE 5

Differences in the metatechnology ratio:
Traditional mountain groves versus traditional plain groves

	Kolmogorov-Smirnov test(1)	*Mann-Whitney test*(2)	*Simar-Zelenyuk-Li test*(3)
	KS-statistic (p-value)(4)	*Z-statistic (p-value)*(4)	*Li-statistic (p-value)*(5)
Radial efficiency	0.6933 (0.000)	-10.296 (0.000)	35.973 (0.000)
Input-specific efficiency			
Labour	0.9449 (0.000)	-13.260 (0.000)	53.238 (0.000)
Machinery	0.5326 (0.000)	-06.913 (0.000)	38.239 (0.000)
Pesticides	0.7925 (0.000)	-10.767 (0.000)	48.268 (0.000)

(1) The null hypothesis is that the distribution of the two samples is the same.
(2) The null hypothesis is that the two samples are drawn from the same population.
(3) The null hypothesis is that the two samples have the same probability distribution function.
(4) Statistics are adjusted for ties.
(5) Original estimates of the MTR are smooth using Algorithm II (Simar and Zelenyuk, 2006: 508; Li, 1996).

Source: Own elaboration.

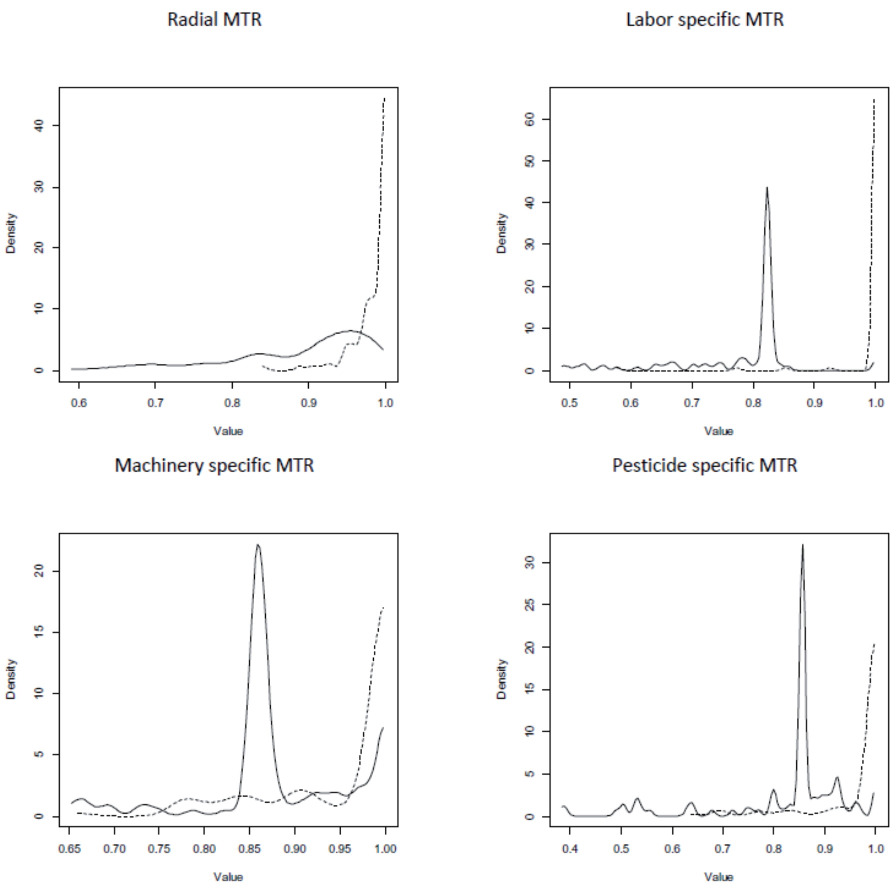
So what can we do to improve technical efficiency? What possibilities does a farmer have to improve? How can an inefficient farm improve its productive outcome? Is it possible for farm managers and agricultural policymakers to take steps to improve farms' efficiency? To what extent can we guide them? Finding answers to these questions is an important challenge and the methodology used in this research can be of help as a guide for either olive growers or public decision makers.

Technical inefficiency reflects the failure of some firms to obtain the maximum feasible output given the amount of input used. However, measurement is not enough to improve technical efficiency (González and Álvarez, 2001). The knowledge-based view recognises inefficiency as a result of lack of knowledge or managerial ability, but farmers have the necessary motivation to become efficient; therefore, learning processes can help to improve efficiency. In doing so, identifying an appropriate benchmark is essential to identify the sources of perceived inefficiencies and to suggest some strategies for efficiency improvement through active learning (González and Cárcaba, 2004). By calculating input-specific directional distance functions, our analysis identifies the shortest way of reaching the technological frontier, as well as the efficient farms acting as peers. These are the benchmarks. By way of example, for the mountain farm#47 input-specific distances to the group frontier are 0.68 for pesticides, 0.48 for labour and 0.46 for machinery. The shortest distance to the frontier is, therefore, in the machinery direction, farm#85 being the peer for farm#47, i.e., the efficient farm to which it is compared. Thus, this may be the farm to visit in an active learning strategy to acquire specific knowledge or managerial skills.

GRAPH 2

Kernel density estimation functions for metatechnology ratios (MTR)

Plain (- - -) and mountain (—) olive grove systems



Source: Own elaboration.

From a more global perspective, analysing efficient farms in relation to inefficient ones can help to guide agricultural policymaking. In the first place, it is worth highlighting that efficient plain and efficient mountain olive groves both record higher levels of production per hectare and lower machinery and energy costs per hectare. In contrast, there are no statistically significant differences where the use of labour, pesticides and fertilisers is concerned. In the second place and in regard to the characteristics of farms, there are no statistically significant differences, in either plain or mountain olive groves, in regard to the size or the age of the farm. As regards planting density, while one could expect greater planting density to increase the efficiency of farms, this result is only obtained in the case of mountain olive groves. In the third place and in reference to the characteristics of the farmers themselves, no differences are found in regard to age, professional training or experience as an olive grower. It is only worth indicating that farmers in efficient farms devote less time to agriculture and also contract less family labour. In view of these results, it is worth recommending policymakers to encourage farmers to contract out certain tasks (phytosanitary treatments, pruning, etc.) to specialised service providers who can perform them more professionally and efficiently in order to enhance the efficiency of olive groves as a whole (Picazo-Tadeo and Reig-Martínez, 2006). In order to do so, policymakers could offer tax benefits for contracting such companies.

5. Conclusions and policy implications

Olive growing is a major agricultural activity in Andalusia that has important economic, social and environmental impacts. However, this farming activity is far from homogeneous, as different types of olive growing systems can be distinguished. Traditional rain-fed plain and mountain olive groves are major systems in Andalusia. Plain olive groves make more intensive use of inputs and, as a result, are more productive than mountain olive groves. The issue of the relative technical efficiency of these systems is therefore not obvious, but essential for the economic viability and environmental impact of this crop. The aim of this research is to compare their relative performance using a sample of farms.

As regards the methodology, we use DEA, directional distance functions and a metafrontier approach (Saéz-Fernández *et al*., 2012). We define alternative efficiency measures using input-oriented and input-specific oriented directional vectors to assess these agricultural systems. In doing so, farms' technical efficiency in regard to the technology of their own group and metatechnology ratios, i.e. group technical efficiency in regard to the metafrontier, are computed.

The empirical results indicate that mountain farmers are more efficient than their plain olive grove counterparts in regard to their respective group technology, regardless of the efficiency indicator we consider. This is the technical efficiency that farmers may be required to improve (Amores and Contreras, 2009) and there is a huge margin to do so. In particular, pesticides perform the worst, while labour is the most efficiently used input in both systems. Furthermore, in regard to the technical efficiency of olive grove systems, traditional plain olive farms are favoured by technological advantages in relation to the conditions faced by mountain farms. The traditional mountain olive grove technology is at a considerable disadvantage, particularly where the input labour is concerned.

This analysis is of particular interest in light of the need to promote an efficient use of inputs, particularly pesticides. In doing so, farmers can improve their economic performance while reducing negative impacts on the environment. Reducing costs is essential in a global context of increased competition in agricultural markets and especially in the olive market, where the extension and intensification of crops has caused major market saturation. The recent fall in olive oil prices makes enhancing efficiency even more necessary in order to maintain the viability of olive farms[14]. However, the available information does not allow us to assess whether farms have made changes in this direction, as we would require information for more periods to do so. The adaptation capacity of farms to changes taking place in the sector is very important and this ability is closely related to the level of education of the farmer. As a result, agricultural training policies are of particular importance when it comes to enhancing efficiency, as is observational learning from efficient farms. Outsourcing of some specialised tasks is another way olive farms might improve their efficiency.

Moreover, significant evidence of mountain olive groves' disadvantages relative to plain olive groves could justify some kind of assistance to this system if maintaining it is considered important for social, cultural or environmental reasons. Nevertheless, this aid should take into account the significant negative externalities that may result from certain farming practices on land with steep slopes, favouring the use of techniques that minimise soil erosion, such as the presence of cover crops or maintaining low walls and terraces. In this sense, training policies and the dissemination of knowledge by observing efficient farmers is important.

Other relevant issues that could provide new avenues of research refer to the potential impact of certain techniques used in land management or harvesting olives on efficiency, considering the case of both mountain and plain olive groves. Additionally, it would be interesting to consider whether it is possible to improve efficiency through organic or integrated farming in regard to traditional farming or whether organic production would be more efficient in mountain olive groves than in plain olive farms.

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[14] Zhu *et al*. (2011) shows that CAP direct transfers had a negative effect on technical efficiency.

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