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Sustainability and multifunctionality of protected designations of origin of olive oil in Spain

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ABSTRACT

Agrarian systems provide sociocultural and environmental externalities, which contribute to the sustainability of rural areas. The aim of this article is to analyse the sustainability of some Spanish olive oil Protected Designations of Origin (PDO) through multicriteria techniques (Analytical Network Process), taking into consideration different farming systems. The analysis has been made through ten criteria grouped in three clusters: economic, environmental and socio-cultural and asked experts. This was done first to rank the criteria and second in terms of what type of farming system achieves these criteria better. According to the results, there is a high level of consensus regarding the criteria ranking and the way that farming systems contribute to agrarian multifunctionality and sustainable development, despite the different characteristics of PDOs. In all cases, organic farming is the best, followed by integrated farming, when achieving economic, environmental and socio-cultural criteria, except for Estepa (where integrated farming is preferred for the economic and socio-cultural criteria). Conventional farming is placed in third position when achieving all functions, except for the environmental criteria, for which abandonment is preferred to conventional farming in all PDOs. Multifunctionality and sustainability are maximized by a combination of farming systems: about 40% organic, 35% integrated, 20% conventional and 5% crop abandonment.

The results of our model regarding the combination of farming systems are similar to the actual situation in the PDOs studied, and, more important, this has been achieved thanks to the PDO institutions. Good local institutions contribute to improve the sustainability of rural areas by encouraging innovation and entrepreneurship (especially in PDOs, triggered by Origin Designation Regulator Councils) and **a** European level, by paying farmers for externalities.

1. Introduction

Agrarian activities provide raw materials and food but also a broad range of positive social and environmental externalities, which contribute to the sustainability of rural areas. By "agrarian multifunctionality" we mean the ability to create a wide variety of outputs, such as externalities and public goods. This term was coined by the European Union at the end of the 1990s and refers to three functions: (a) agrarian production, (b) the preservation of rural areas and their landscapes and (c) the contribution to the social feasibility of rural areas.

The cultivation of olive groves, which exceeds 2.5 million ha in Spain, is important not only from an agrarian perspective but also in regards to the regional landscape, natural and cultural heritage and environmental management. Therefore, olive farming provides a potentially suitable study-case to analyse the multifunctional behaviour of agricultural systems. However, little work has been done on the sustainability of olive oil qualified by Protected Designations of Origin (PDO), the agencies that certify the highest quality olive oil in the EU. Additionally, although there are no previous studies comparing the situation of other geographical areas in Spain outside Andalusia, the national leading producer of olive oil, initial observation suggest differences in economic, environmental and social characteristics across regions.

The aim of this article is to analyse the sustainability of some Spanish olive oil PDO through multicriteria techniques and by taking into consideration different farming systems.

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Quite possibly, olive oil producers are not aware of the positive externalities they generate. In this article, we argue that the economic profitability (from a social perspective) of olive oil production under a PDO is higher than the financial profitability (from a private perspective). For this, we have used the analytic network process (ANP) and tested some methodological variations in terms of a number of Spanish olive oil PDOs. As a result, the generation of externalities by different farming options (organic, integrated, conventional and abandonment) is analysed.

A series of articles on this topic have been written in the last few years with different methodological approaches. In this regard, Kallas et al. (2006), Kallas and Gómez-Limón (2007), Gómez-Limón et al. (2007), Arriaza et al. (2008) and Gómez-Limón and Barreiro (2012) analyse characteristics of olive groves by applying the choice experiment methodology. With this methodology, Villanueva et al. (2015a) design tools to promote agricultural public goods production. Others, like Marangon et al. (2008), evaluate the landscape composed of hillside olive groves in the Slovenian region of Goriska Brda applying the contingent valuation method. Fleskens et al. (2009) value the role played by the functions of agricultural olive grove ecosystems to plan accordingly in the hills of northeastern Portugal. Meanwhile, Gómez-Limón and Riesgo (2012) propose a set of multifunctional representative indicators to analyse the sustainability of various Andalusian olive grove zones.

By means of the analytic hierarchy process (AHP), Parra-López et al. (2005, 2007, 2008) and Villanueva et al. (2014a,b) address externalities and public goods generation in different olive grove systems and for different farming decisions and structural features. They analyse the economic, technical, sociocultural and environmental functions of olive groves. The same methodological framework is applied by Gómez-Limón and Arriaza (2013) to analyse the social preferences of different features of Andalusian rural areas. Arriaza and Nekhay (2010) combine the AHP tools and its generalization, the ANP, and apply them to Andalusian poorer olive oil producing groves. Carmona-Torres et al. (2011), Pérez y Pérez et al. (2013), Carmona-Torres et al. (2014) and Villanueva et al. (2014b) have all used the same methodology to analyse the sustainability of good agricultural practices, the productive systems in different territorial areas and the influence of management factors in the production of public goods of Andalusian olive groves. Villanueva et al. (2015b) discuss the contribution of relevant economic actors to the provision of private and public goods in three European agricultural landscapes.

From the works quoted above, it can be concluded that, in Andalusia, the relationship between productive activity, sustainability and the generation of positive externalities depends on farming practices, the physical and territorial features of olive groves and different types of cultivation. From a methodological point of view, it is acknowledged that other conclusions could be derived, especially if additional regions, farming systems or olive oil PDO producing areas were considered. It is apparent that more empirical research, applying different methodological frameworks and available analytical techniques, is needed to deepen the understanding of the impact on sustainability of different olive oil grove systems in different Spanish regions.

2. Case study

Spain occupies first place in the world ranking of olive grove and olive oil production, representing 45% of world production and 60% of European Union (EU) production. In 2014, the area devoted to this crop was 2,515,751 ha, of which approximately 72% was grown on dry land. The average production in the last six harvests exceeded 1.2 million t (Magrama, several years, 2016). It is worth highlighting that, during the past decade and despite the progressive reduction of the cultivated area, average production increased by 23%, mainly due to the rise of superintensive irrigated farms.

Of the 2.5 million ha of Spanish olive groves, 688,245 are registered by the 28 olive oil PDOs existing in Spain. The food quality certification under PDO is established by EU regulation and ensures some quality requirements that are higher than those required for other food products. Foods covered by PDO are those whose quality and characteristics are due to the geographical environment, with its natural or human factors. Their production and processing are always carried out in the delimited geographical area that gives them their name.

The empirical analysis has been applied to four different olive oil PDOs: Estepa, Sierra Mágina and Sierra de Segura in the Andalusian region (South of Spain) and Bajo Aragón (northeastern Spain). According to Magrama (2015), these four PDOs represents 156,710 ha of olive groves (22.8% of the area of olive groves in Spain) and host 103 oil mills (28% of the total). They certify and sell around a quarter of all Spanish olive oil under PDOs for an amount that exceeded € 34.6 million in 2014 (Table 1).

These PDOs have different agronomic, economic, environmental and social features. For instance, Sierra de Segura and Sierra Mágina have farms with steep slopes, typical of mountain olive groves, with very limited possibilities for mechanization and medium and low yields per ha. By contrast, the landscapes in Aragón and Estepa correspond more with the countryside and the rolling hills of lower altitudes. While in Estepa, minor mechanization and lack of irrigation hamper olive yields, in Aragón, a harsh climate, with little chance of irrigation, and the low productivity of traditional local olives pose a threat to the survival of the olive groves that in fact are gradually being abandoned.

Similarly, the greater potential for irrigation of olive farms and varieties of highly productive local olive in Andalusian PDOs makes average farm productivities much higher than those observed in Bajo Aragón. This is due to the spread of native varieties with very low yields in dry lands. Finally, most of the economic activity in the mountains of Sierra de Segura and Sierra Mágina revolves around the olive groves, which are by far the most important in both PDOs. However, in Bajo Aragón and Estepa, the economy is much more diversified among other agricultural, industrial and service branches, and, therefore, the economy in both PDOs is not as dependent on olive-growing activity.

Moreover, as the relationship between olive grove production and the generation of externalities depends on the type of farming system, we analyse the provision of externalities in PDOs offered by each farming system: organic, integrated, conventional and abandonment.

The organic farming system is the most respectful of the environment and also provides the most positive externalities for society. Nevertheless, the share of this farming system in Spanish olive oil PDOs is still very limited, except for in Sierra de Segura.

The integrated system is a farming model that minimizes the use of agrochemicals and seeks maximum food safety. This system is particularly widespread in the whole of Andalusian agriculture. Integrated Andalusian olive groves occupy almost 400,000 ha; this system is more environmentally friendly than conventional agriculture and obtains higher yields per ha than organic farming. Estepa is a good example of an Andalusian olive oil PDO where the integrated system is clearly predominant.

The conventional or traditional farming system is one that, based on a high consumption of agrochemicals, aims to ensure and maximize its financial feasibility, regardless of its negative effects on the environment. In Bajo Aragón, this production system is the most representative, having a limited presence of organic and integrated systems in this PDO.

Finally the abandonment of olive groves has also been considered in the analysis. Although it is not strictly a production system,

Table 1
Characteristics of Spanish PDOs: surface, production and commercialization.

Olive oil PDO	Surface (ha)	Oil mills (number)	Certified production by PDO (t)	Sales with PDO label (t)	PDO price (€/l)[a]	Sales PDO (million €)
Bajo Aragón	22,000	32	4,000	1,900	4.5	8.6
Estepa	38,248	19	20,000	3,000	5.0	15.0
Sierra de Segura	36,462	24	1,803	806	3.8	3.1
Sierra Mágina	60,000	28	9,200	2,100	3.8	8.0
Total case study	156,710	103	35,003	7,806	4.3	34.6
Total Spanish olive oil PDO	688,245	368	144,423	29,196		128.6

Source: Magrama (2015).
[a] Average litter selling price in the origin of bottled olive oil with a PDO label in 2014.

nowadays it is a reality in some parts of Spain, such as in Bajo Aragón, with serious economic, environmental and social consequences. In fact, there is a gradual abandonment of a large number of small olive farms because of a lack of profitability. Thus, the surface of olive groves in Spain in 2014 declined by 68,813 ha compared to the previous year (Magrama, several years, 2016).

3. The ANP modelling approach

Saaty, the creator of ANP, designed the methodology with the purpose of making decisions by taking into account several criteria and alternatives all at once (Saaty, 2001). These criteria and alternatives, referred to as elements, are grouped into clusters. Each element may influence other elements of a network, not only elements of the same cluster but also elements belonging to different clusters. The influence of elements in a network on other elements in that network can be represented with a supermatrix. This new concept consists of a two-dimensional element-by-element matrix, which adjusts the relative importance weights in individual pairwise comparison matrices to build a new overall supermatrix with the eigenvectors of the adjusted relative importance weights (Aragonés-Beltrán et al., 2008). This quality of ANP involves working with interdependent criteria and alternatives and provides a precise tool to model real and complex problems. The theoretical full description is available in Saaty (2001, 2005). From a practical point of view and following Aragonés-Beltrán et al. (2008), the main steps of the ANP modelling approach can be summarized as:

- I Identifying the components and elements of the network and their relationships.
- II Conducting pairwise caparisons on the elements.
- III Placing the resulting relative importance weights (eigenvectors) in pairwise caparison matrices within the supermatrix (unweighted supermatrix).
- IV Conducting pairwise comparisons on the clusters.
- V Weighting the blocks of the unweighted matrix by the corresponding priorities of the clusters so that it can be column-stochastic (weighted supermatrix).
- VI Raising the weighted supermatrix to limiting powers until the weights converge and remain stable (limit supermatrix).
- VII Obtaining the element prioritizations according to any of the columns of the limit supermatrix.

The method proposed in this work to analyse the sustainability of Spanish olive oil PDOís is show in Fig. 1.

To determine which combination of farming systems maximizes the sustainability of Spanish olive oil PDOs, at the stage of problem analysis, the first question is to establish what externalities will be taken into account. After a review of the literature on agricultural externalities that was agreed on with agronomists, environmentalists and social scientists, ten criteria were finally selected and grouped into three clusters: economic, environmental and socio-cultural. Also, a fourth cluster is the alternatives of farming options: organic, integrated, conventional and olive grove abandonment (Table 2).

In the phase of data synthesis, the ANP is applied to build the decision-making problem model. Once the elements (criteria and alternatives) have been identified and grouped into clusters, the next step is to determine their influences on each other and place all this information in a matrix. To determine the influences to be considered, a review of the literature on agrarian multifunctionality and sustainable development was made, and the influences taken into account were agreed on by a few experts who will assess them later on. Table 3 shows the matrix of influences between the criteria and alternatives, where both rows i and columns j are the aforementioned criteria and alternatives respectively. Cell n_{ij} takes the value 1 when the element in the raw i influences the element in column j and takes 0 otherwise.

This means, for instance, that *income* (first raw) has an influence on *population* because it is a crucial element for people to decide where to live. Furthermore, for farmers to decide between alternatives (last four columns), *income* is one important criterion. In fact, all criteria have been selected because farmers take them into account when choosing the type of cultivation.

The amount of *income* (first column) is influenced by the *quality* of the olive oil, its *safety* and the capability to sell it (*commercialization*). Good institutions (*governance*) are able to create a good social climate to produce better olive oil. And finally, other valuable goods, such as the landscape or cosmetic products (*heritage*), can contribute to generate *income*. Alternatives have also an influence on the criteria. The amount of *income* obtained from an olive grove depends on the farming system, not only in terms of the prices of olive oil being different but also in terms of the costs to produce it. Again, all alternatives influence all criteria.

To facilitate experts in prioritizing between elements, a conventional ANP questionnaire was designed in order to assess how each element influences those to which it is related. Experts were asked to compare pairs of elements in relation to a third criterion, which acts as a control.

The selection of experts to be consulted is a crucial element of the analysis in order to avoid biases, given that the value they assign to both criteria and clusters has a strong subjective component. In our case, we tried to find a relatively large number of people, looking for a balance between local experts – who know the field in the sphere of each of the olive oil PDO – and researchers of social sciences with proven experience in the area of olive grove systems, rural multifunctionality and sustainable development. Finally, a total of 61 experts were interviewed between the winter of 2011 and the spring of 2015. They were chosen from amongst technicians from the Regulatory Councils of PDOs, agrarian regional offices, agrarian professional organizations, organic consumer and farmer associations, groups for rural development, cooperative and private oil mills and researchers from several Spanish Universities.

Answers were placed in a matrix as explained in step (ii) of this section (pairwise comparison matrix). Upon completion of all pair wise comparison matrices, the unweighted supermatrix was

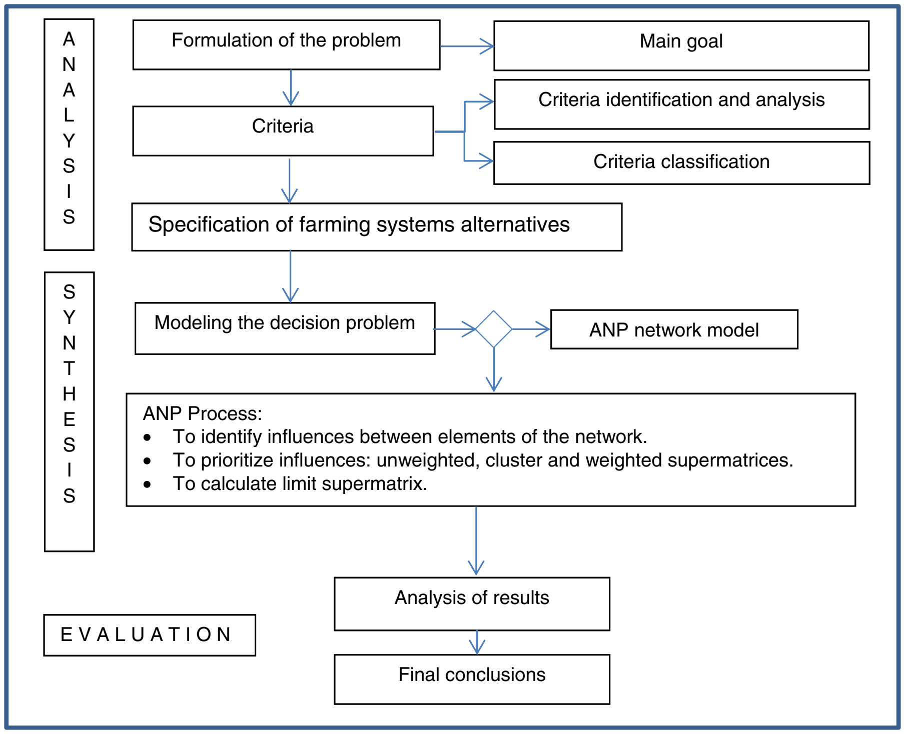

Fig. 1. Evaluation model for the sustainability of Spanish olive oil PDOs.
Source: adapted from Aragonés-Beltrán et al. (2010), Giner-Santoja et al. (2012) and Cannemi et al. (2014).

Table 2
Clusters and criteria.

Cluster	Abbreviation	Definition
Economic	Income	A standard indicator composed of all income directly related to olive cultivation and olive oil production
	Quality	The manner in which the type of farming and agrarian practices affect the quality of final products
	Commercialization	The capability of agents and companies in a certain territory to improve the distribution of olive oil in the local, national and international markets
	*S*afety	Safety is understood in sanitary terms and implies that households have access to healthy food, resulting in active and healthy lives
Environmental	Erosion	The fight against soil erosion and degradation by adopting good agrarian practices, for example introducing vegetal soil covers
	Contamination	Reduction in soils and aquifers involves using minimum quantities of pollutants, such as fertilizers, pesticides or weed-killers, all of which reach water sources via various channels
	Biodiversity	Preservation of the existing variety of biological species is key to achieving a sustainable development model, which minimizes the negative effects caused by human activity
Socio-cultural	Population	The establishment of a rural population is a result of olive cultivation because it generates employment and income for families in rural areas and slows depopulation
	Governance	Refers to the promotion of relationships between stakeholders (institutions and social agents), which may encourage innovation and entrepreneurship, as well as harmony in the decision making process. It also could contribute to a good social atmosphere
	Heritage	Actions directed towards the assessment of the cultural and natural heritage of the olive industry help to promote other productive activities related to olive groves, such as tourism, gastronomy, cosmetics, craftwork, etc.
Farming systems	Organic	It is a farming system based on the use of natural resources, without using synthetic chemicals or genetically modified organisms, to ensure the fertility of the land and respect for the environment.
	Integrated	A farming model that minimizes the use of agrochemicals and seeks maximum food safety
	Conventional	A farming system based on a high consumption of agrochemicals, aiming to ensure and maximize financial feasibility, regardless of its negative effects on the environment
	Abandonment	Although not strictly a farming system, it is a fact of many rural areas because of the lack of profitability, with serious economic, environmental and social consequences

Table 3
Matrix of influences between elements (criteria and clusters).

Clusters	Criteria	Economic				Environmental			Socio-cultural			Alternatives			
		1	2	3	4	5	6	7	8	9	10	O	I	C	A
Economic	1. Income								1			1	1	1	1
	2. Quality	1		1						1	1	1	1	1	1
	3. Commercialization	1	1							1		1	1	1	1
	4. Safety	1		1								1	1	1	1
Environ-mental	5. Erosion				1		1	1			1	1	1	1	1
	6. Contamination				1	1		1			1	1	1	1	1
	7. Biodiversity										1	1	1	1	1
Socio-cultural	8. Population											1	1	1	1
	9. Governance	1	1	1	1	1	1	1	1		1	1	1	1	1
	10. Heritage	1							1			1	1	1	1
Alternatives	Organic	1	1	1	1	1	1	1	1	1	1				
	Integrated	1	1	1	1	1	1	1	1	1	1				
	Conventional	1	1	1	1	1	1	1	1	1	1				
	Abandonment	1	1	1	1	1	1	1	1	1	1				

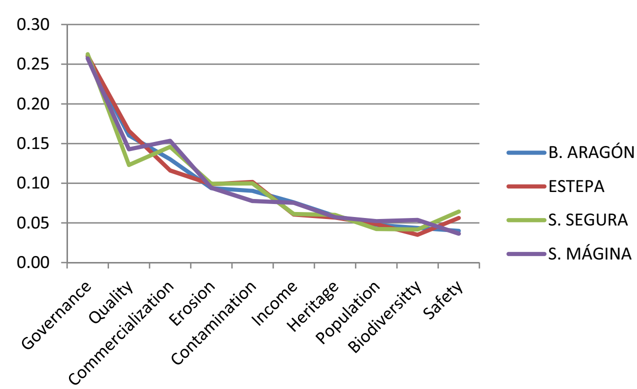

Fig. 2. Priorities of criteria for the olive oil PDOs.

built. The corresponding priorities have been also obtained through the questionnaire and used to weight the matrix and build the weighted supermatrix. By raising the weighted supermatrix to limit powers until the weights converge and remain stable, the limit supermatrix was achieved (Cannemi et al., 2014).[1]

4. Results

In this phase of evaluation, we can firstly see how the experts of each olive oil PDO organise the criteria according to their importance to chose the farming alternatives. The analysis of the PDOs has been carried out assuming that all of them have the same importance (*i.e.* value 1 in Saaty's scale).

According to Fig. 2, there is a high level of consensus regarding the most important functions of the olive groves: *governance* (socio-cultural), *quality* and *commercialization* (both economic). We can construct the following decisional polynomial (variables and weights), which maximizes the sustainability:

Sustainability = *f* [26% *governance*, (12–17)% *quality*, (12–15)% *commercialization*, (9–10)% *erosion*, (8–10)% *contamination*, (6–8)% *income*, 6% *heritage*, (4–6)% *safety*, (4–5)% *population*, (4–5)% *biodiversity*].

The range of weights (minimum and maximum weight of each criterion in the four PDOs) is sufficiently narrow to state that all the experts, regardless of origin area, make their decisions having the same scheme in mind.

Second, we address to what extent the farming system alternatives achieve economic, environmental and socio-cultural functions, according to the experts. In Fig. 3, it should be noted that the height of the bars does not directly correspond to the proportion of land dedicated to each of the types of cultivation. In exchange, it is easier to deduce certain empirical regularities.

The following can be stated:

- Regarding the farming system alternatives, experts agree that organic farming is the best for all functions except in Estepa, where, apart from environmental purposes, they clearly prefer integrated farming.
- There is a high level of consensus when considering the conventional system as the worst, even for economic functions.
- It is remarkable that the abandonment of olive grove is better than conventional farming for environmental functions.

It is worthwhile to take a closer look at each function bloc to determine the reasons for the types of crop arrangement in each PDO. Starting with the economic cluster, Fig. 4 shows the extent that each system alternative is useful in achieving the criteria of *income*, *quality*, *commercialization* and *safety* for each PDO.

According to the Estepa experts, the integrated system is the best type to achieve the criteria, whereas Sierra de Segura experts prefer the organic system. The experts in Bajo Aragón and Sierra Mágina do not have clear preferences; the integrated system is better to obtain *income* while, for *safety* purposes, the organic system is more suitable. But it is advisable to focus on the two most important criteria: *commercialization* and *quality*. To achieve them, Bajo Aragón and Sierra Mágina experts prefer the organic system.

However, it is remarkable that the existing consensus is that *income* is not maximized through the conventional system. The experts state that the oil produced through organic and integrated systems is sold at higher prices, which exceed the higher costs of production.

Regarding the environmental criteria, the relative importance given by the experts is: *erosion*, 9–10%; *contamination*, 8–10% and *biodiversity*, 4–5%. See Fig. 5 for a summary.

Fig. 5 shows that, to improve the environmental criteria, the organic system is preferred, apart from Estepa in the case of biodiversity. For this, they opt for the integrated system. It should be considered that the organic system has strict regulations in terms of the quantities of chemical products used, such as fertilizers and pesticides, but it is no different from the other systems regarding the agricultural practices that reduce *erosion* or preserve *biodiversity*. In fact, some experts stated in the interviews that the integrated

[1] All mathematical calculations were implemented through the free software Superdecisions developed by Saaty (www.superdecisions.com).

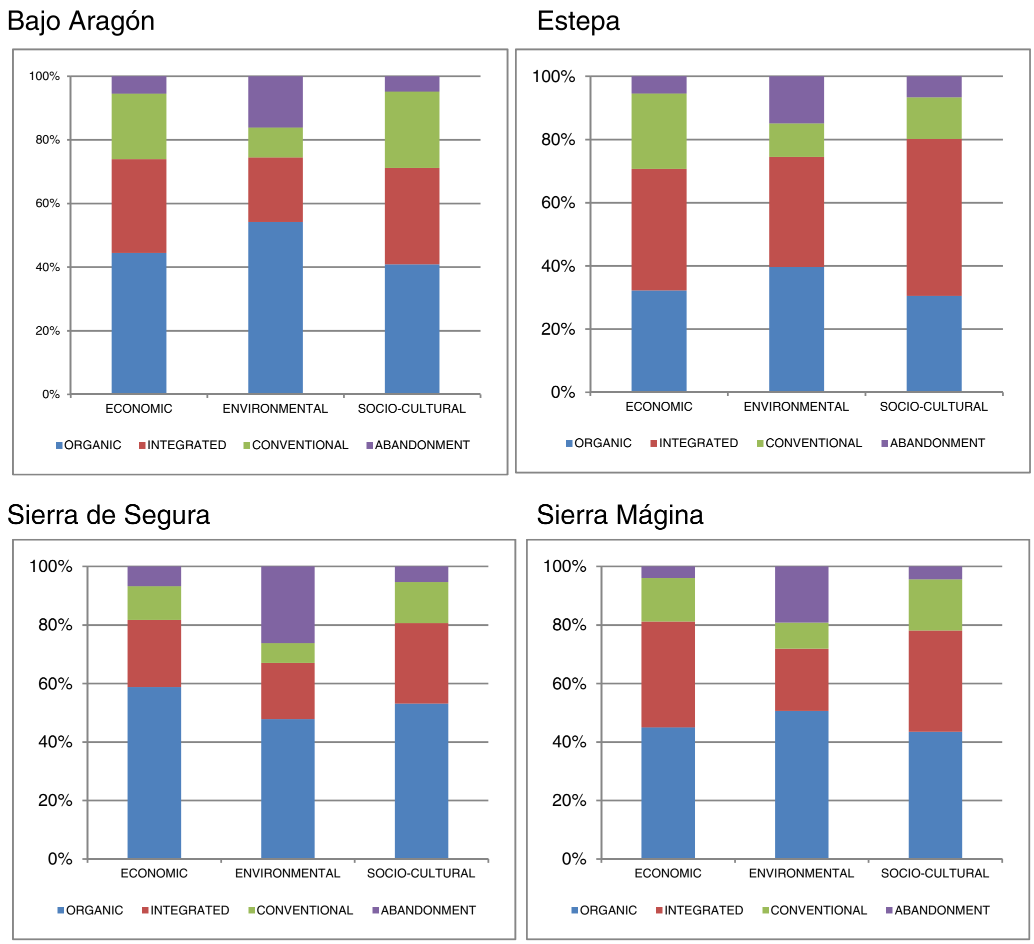

Fig. 3. The importance of the types of farming achieving function groups.

system is better in avoiding erosion because it does not allow certain practices that destroy the soil cover. However, others argued that farmers who engage in organic farming have more awareness about environmental issues, and, therefore, they take care of the soil cover and maintain biodiversity even if they are not regulated to do so.

In fact, although the integrated system is ranked after the organic system for reducing erosion and improving biodiversity, to avoid contamination, all experts agreed that the abandonment of olive groves is even better than the integrated system. Furthermore, for erosion and biodiversity purposes, they stated that it is better to abandon olive groves than to farm using the conventional system. In short, the conventional system is at the bottom of the list to meet environmental functions.

Finally, comparing the four areas with regards to the socio-cultural functions (Fig. 6), we found that the order and weights of these criteria are *governance*, 26%; *heritage*, 6% and *population*, slightly higher than 4%.

It is within the socio-cultural criteria that the expert opinion most diverges. Clearly, in Estepa, they decide in favour of the integrated system, and, in Sierra de Segura, in favour of the organic system. Nevertheless, in Bajo Aragón, they believe that all types of farming systems are equal in boosting *governance*, whereas, in Sierra Mágina, only the organic and integrated systems are able to boost *governance*. In both PDOs, *population* could be maintained both with organic and integrated systems, and the organic system is considered to be better in preserving *heritage*.

In the end, however, the choice between types of agricultural systems is determined by the one, which contributes the most to *governance* because *heritage* and *population* barely have an influence on decisions. In this respect, in Bajo Aragón, experts believe that the type of cultivation is hardly material; in Estepa, the integrated system is strongly preferred; in Sierra Mágina, both organic and integrated systems work well and, finally, without a doubt, in Sierra de Segura, the organic system is best.

Finally, we address the farming system mix that maximizes the multifunctional polynomial. See Fig. 7.

Experts do not agree on the optimum farming system to maximize the multifunctionality and sustainability of Spanish olive oil PDOs. The three most important criteria according to the experts consulted are summarized in Table 4.

Adding in the rest of the criteria (*erosion*, *contamination*, *income*, *heritage*, *population*, *biodiversity* and *safety*, in order of importance) and the best farming alternatives to meet these criteria, the experts agree on which types of farming systems guarantee olive grove sustainability, organic and integrated, but not all agree to the same extent. While, in Andalusian PDOs, they support farming systems that preserve the environment, Bajo Aragón relies slightly more on the conventional system (Table 5).

It is remarkable that, while the experts share beliefs regarding the most important olive grove functions, they vary in terms of how to achieve these functions. But above all, Sierra Segura prefers the organic system, Estepa prefers the integrated system and Bajo Aragón prefers the conventional system. Amongst Andalusian experts, it is believed that 77% of olive groves should be organic or integrated to maximize their functions – properly weighted. Although in Aragón, it is not much different, there is a greater preference – in relative terms – for the conventional system, 7–9

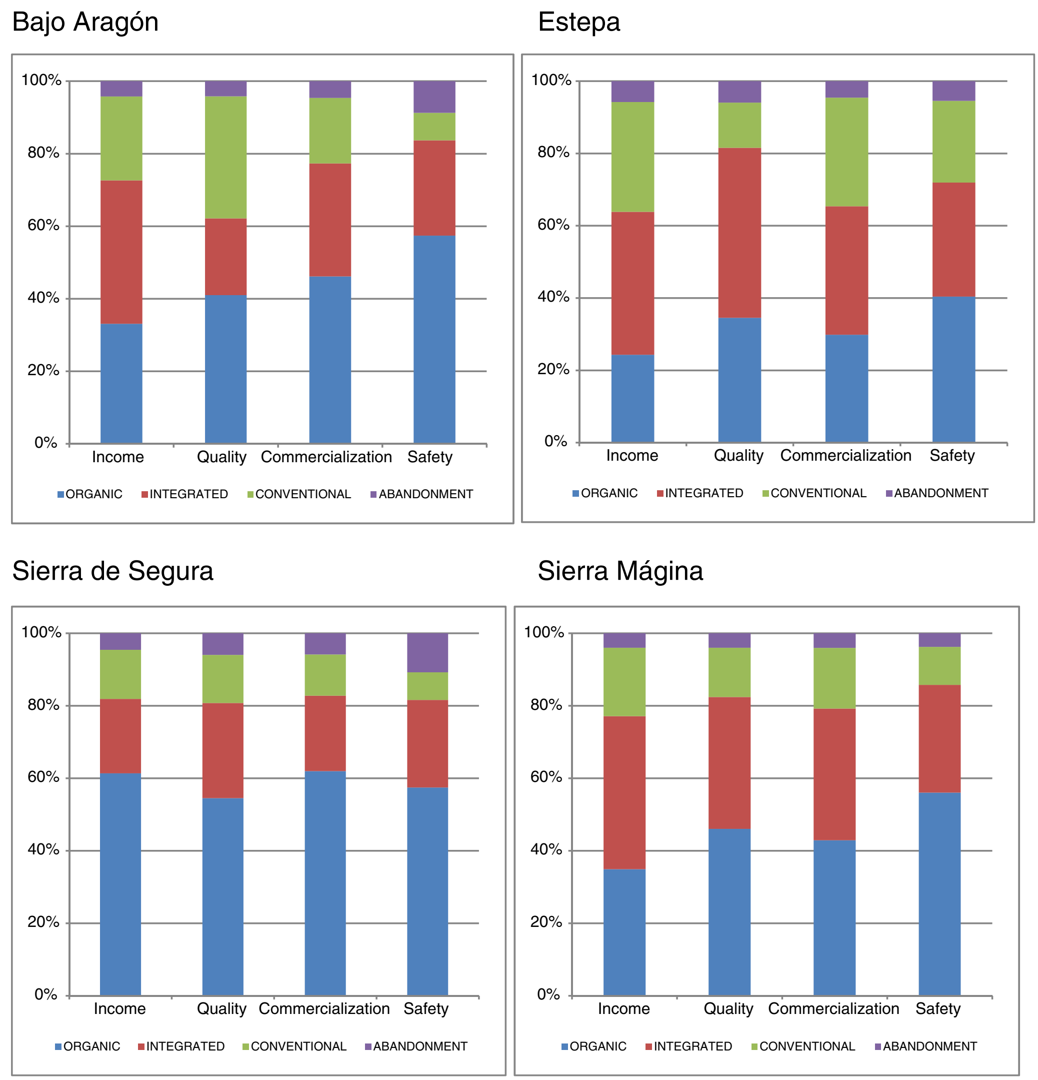

Fig. 4. The importance of the type of farming system in economic function achievement.

Table 4
Preferred farming systems in olive oil PDOs to achieve *governance*, *commercialization* and *quality*.

	Governance	Commercialization	Quality
BAJO Aragón	Irrelevant	Organic	Organic
Estepa	Integrated	Integrated	Integrated
Sierra Mágina	Organic and integrated	Organic and integrated	Organic and integrated
Sierra de Segura	Organic	Organic	Organic

Table 5
Preferences regarding farming system alternatives in the 4 PDOs (shares).

	B. Aragón	Estepa	S. Segura	S. Mágina
Organic	42%	33%	52%	42%
Integrated	27%	44%	25%	35%
Conventional	23%	16%	13%	16%
Abandonment	8%	7%	10%	7%

percentage points higher than within Andalusian PDOs; however, the combination of organic and integrated is 7 points lower, at 70%.

The results of the model are similar to the actual farming system combination in each area and have a high relationship with institutional matters and especially *governance*. Thus, for example, in Estepa, almost all olive cultivation is carried out using integrated farming and a second degree cooperative gathers most of the bottled olive oil from the farmers. In Sierra de Segura, another PDO using mono-cropping almost exclusively, as in Estepa, the organic system is increasingly catching on, since the end of the last century. Nevertheless, in the countryside of Bajo Aragón, where the most pressing problem is demographic regression, olive groves are by no means the monoculture, and they use non-irrigated and irrigated crops; here, the conventional system prevails, and organic farming is purely symbolic. Moreover, attempts by regional administrative authorities to unite the commercialization of olive oil have failed.

5. Sensitivity analysis

In the model, we have presented criteria, which have been grouped in three clusters. However, we explore to what extent the results are affected by the way the criteria are grouped or by the importance that a cluster has in comparison to others. First, the

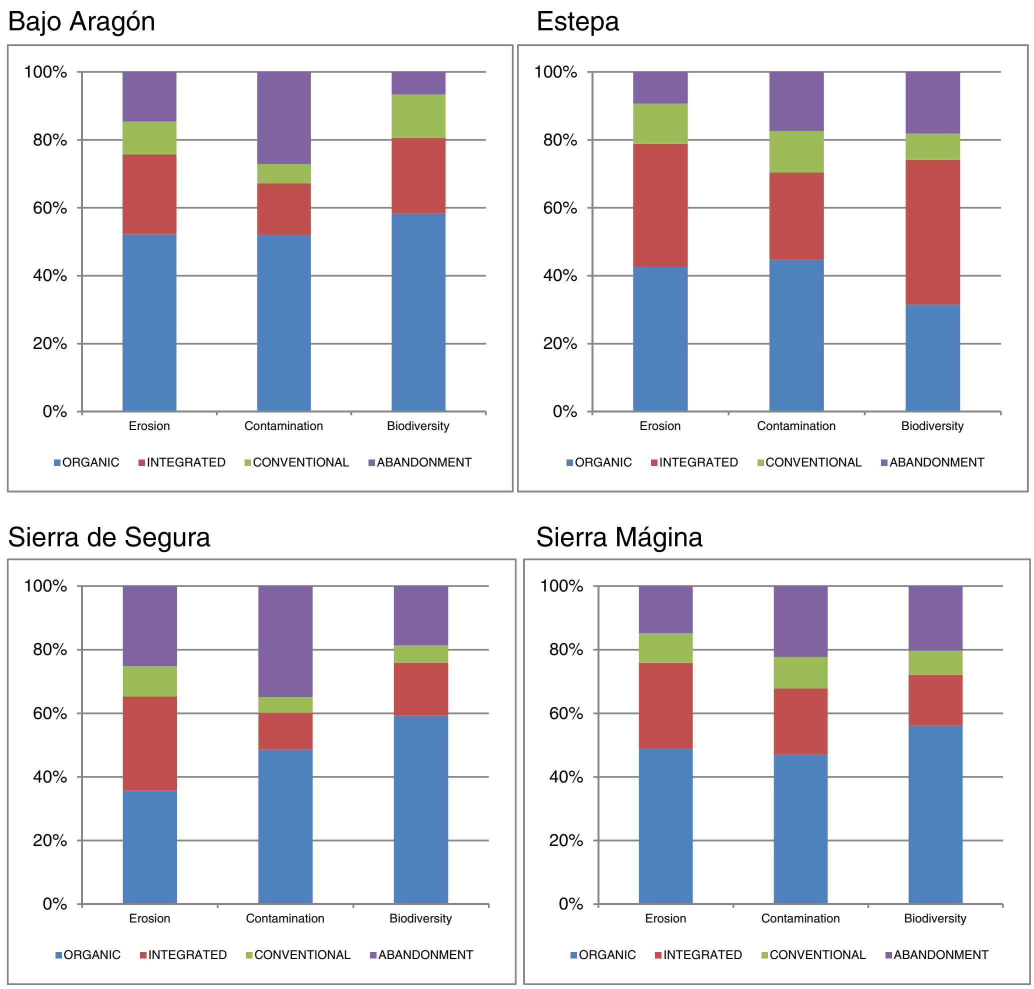

Fig. 5. The importance of the type of farming systems in environmental function achievement.

change in the number of clusters is discussed and then the change in the relative weighting of clusters.

5.1. Number of clusters

We made three different models. In the first, all criteria were grouped in one cluster, except for the farming systems, which always were placed in a separate cluster. When we grouped all criteria into two clusters, the first consisted of the economic criteria (*income*, *quality*, *commercialization* and *safety*), and the rest were in the socio-environmental cluster. Finally, the model with three clusters is the one we have already demonstrated, the first with the economic criteria (*income*, *quality*, *commercialization* and *safety*), the second with the environmental criteria (*erosion*, *contamination* and *biodiversity*) and the third with the socio-cultural criteria (*population*, *governance* and *heritage*).

The differences between the results of these models come from the fact that pairwise comparisons between criteria belonging to different clusters are not allowed. If compared criteria belong to the same cluster the weight in the weighted matrix is shared among these criteria according to the experts' preferences. Nevertheless, if criteria belong to different clusters, the program assigns the weighting of a cluster to each criterion. Therefore, the larger the number of clusters (thus, less criteria in each one and more probability of pairwise comparisons between criteria belonging to two different clusters), the greater the weighting of some criteria. This is the case for *governance*, as shown in the Influences matrix (Table 3), but this is not the only case.

To illustrate, we have studied as an example a comparison between three criteria – *erosion*, *contamination* and *governance* – with respect to a third control criterion – *safety* – in the Sierra Mágina PDO. With one and two clusters, all the comparisons are internal; however, with three clusters, *erosion* and *contamination* belong to the environmental cluster while *governance* belongs to the socio-cultural cluster. For the purpose of this exercise, the same weight has been given to all clusters.

Table 6 shows the weighted matrix figures when comparing these criteria in the cases of one, two and three clusters.

As can be seen, when criteria belong to the same cluster (in both cases if we gather all criteria in one or two clusters), their influence with respect to *safety* (see columns 1 and 2) is less than if *erosion* and *contamination* belong to the same but *governance* to a different cluster (column 3). The influence of all criteria increases but, as has been said, the amount of the increase is not the same for all three. It is noticeably higher for *governance*, and this has an effect also in the limit matrix (at the expense of the others, of course).

Fig. 8 indicates the differences among the weighting of the criteria depending on the number of clusters of the four PDOs. Notably, the effect already explained for *governance* is visible in all cases; the higher the number of clusters, the greater the importance.

In spite of this effect, we can state that changes in the number of clusters barely affect the criteria order, if at all. And this is true for all of the PDOs. Only the *quality* and *safety* criteria, ranked very closely

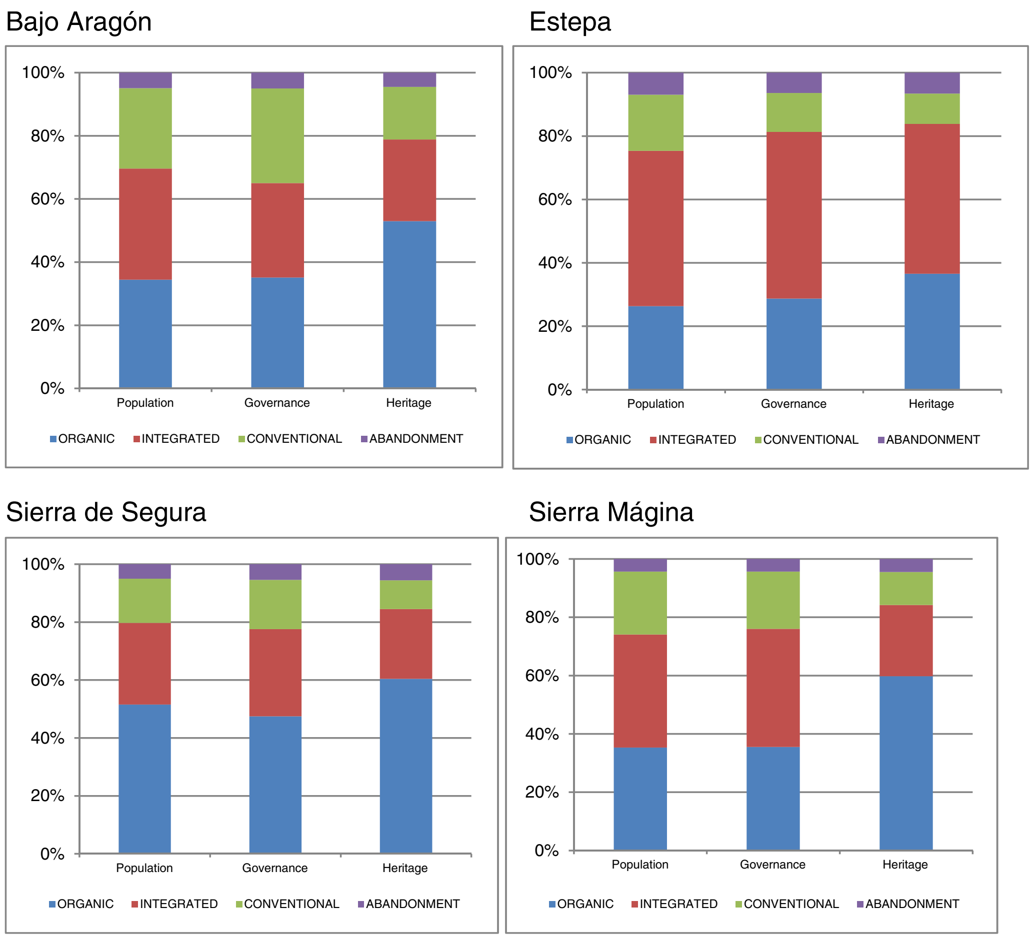

Fig. 6. The importance of the type of farming in socio-cultural function achievement.

Table 6
Sierra Mágina. Weighted matrix elements with one, two and three clusters.

	(1) Weighted 1 Cluster Safety	(2) Weighted 2 Clusters Safety	(3) Weighted 3 Clusters Safety	(4) = (3)/(2) Change %
Erosion	0.105393	0.105393	0.118280	12.23
Contamination	0.187802	0.187802	0.215054	14.51
Governance	0.206805	0.206805	0.333333	61.18

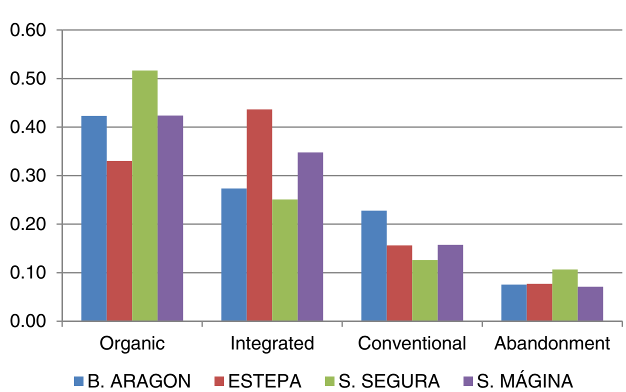

Fig. 7. System alternative priorities in the olive oil PDOs.

Table 7
Cluster matrix.

	Economic	Environmental	Socio-cultural	Alternatives
Economic	0.25	0	0.25	0.33
Environmental	0.25	0.33	0.25	0.33
Socio-cultural	0.25	0.33	0.25	0.33
Alternatives	0.25	0.33	0.25	0

to each other, sometimes alternate. Therefore, we decided to group criteria in three clusters according to the following externalities classification produced by olive groves: economic, environmental and socio-cultural. In addition, as can be seen in Fig. 1, the order is basically the same in all geographic PDOs.

Regarding the order of criteria, both Aragonian and Andalusian experts agree on the first three, *governance*, *quality* and *commercialization*, when choosing between farming system alternatives (see also Fig. 1). Despite *governance* being somewhat overvalued, there is such a big difference between *governance* and quality and commercialization that we can accept it as the most important.

Income follows after the two environmental criteria of *erosion* and *contamination*, which may seem surprising. Experts believe good *governance*, boosted by good *quality*, would be easier to Commercialize and, as a result, *income* will increase.

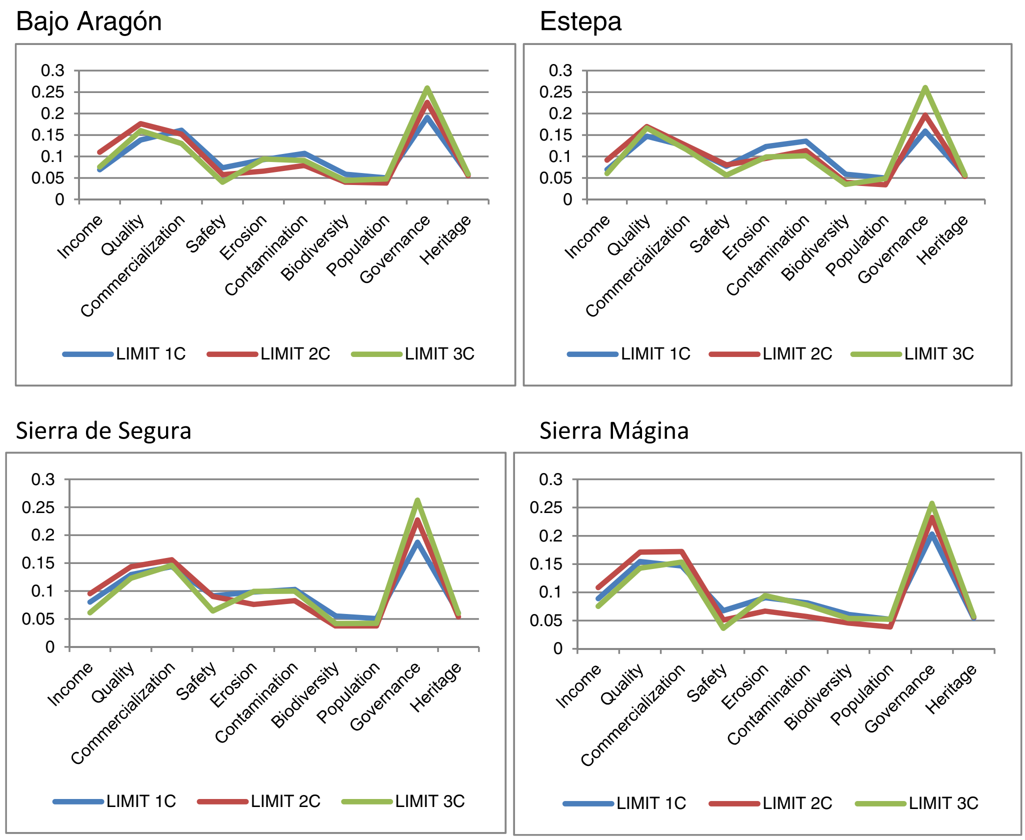

Fig. 8. Comparison criteria priorities according to the number of clusters.*.

Finally, *safety* being ranked the lowest is explained by experts assuming that olive oil produced under PDOs meets high standards because of PDO controls. Therefore, experts value the rest of criteria more than *safety*.

5.2. The relative importance of clusters

The results of farming alternatives depend on the relative valuation that experts give to criteria and on the valuation given to the clusters in comparison, in other words, to what extent a cluster is more important than others according to Saaty's scale. In our case, assuming that all of them have the same importance means assuming that, when experts decide between system alternatives, they think, for example, that environmental criteria are as important as economic criteria. When comparing criteria, experts are able to say that economic criteria must be present to continue with the activity and, thus, that these criteria are more important than environmental and socio-cultural criteria. But the same weight to all clusters will be assigned by the software if no inputs are introduced. In our case, even if experts give minor importance to environmental criteria related to economic criteria when choosing between system alternatives, the effect of the cluster matrix will reduce this difference. Table 7 shows the cluster matrix of the three clusters model.

The effect of changes in cluster weighting on results has been analysed by means of three scenarios. The first corresponds to Table 3 matrix where all clusters have the same weight (S1); in the second one, the economic cluster is a little more relevant than the environmental and the socio-cultural clusters (Saaty scale) (S2); finally, in the third, the environmental cluster is slightly more relevant than the other clusters (S3). The results of this analysis can be seen in Fig. 9. In order to be brief, it shows only data for Sierra Mágina. Results are similar for the other PDOs.

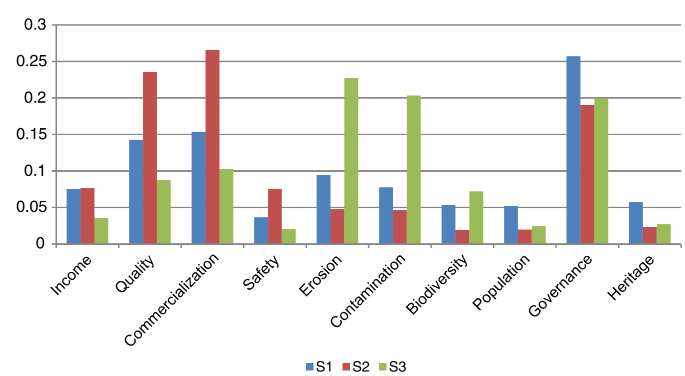

Fig. 9. Criteria priorities under different scenarios for Sierra Mágina.

Depending on the scenario, the order of criteria and relative importance is clearly different. Under S2, economic criteria, especially *quality* and *commercialization*, have increased their importance at the expense of environmental and socio-cultural criteria. The same occurs under S3, where *erosion* and *contamination* appear with a higher weighting. However, the combination of farming types to meet all functions has not been modified according to experts. See Fig. 10 also for Sierra Mágina.

In Fig. 10, a fourth scenario (S4) in which the economic cluster is considerably more relevant (5 on the Saaty scale) than the others (environmental and socio-cultural) has been added to confirm the stability of the results. As can be seen, the mix of farming alternatives has barely been modified. This kind of sensibility analysis

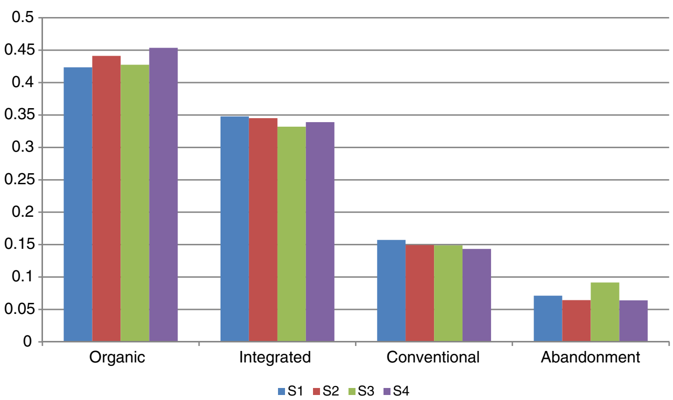

Fig. 10. Alternative priorities in Sierra Mágina under several scenarios.

has also been made for the other three PDOs, and conclusions are similar.

Consequently, since the effect of changes in the relevance of clusters in the mix of farming alternatives is so small, t scenario S1 was chosen (1 on the Saaty scale: all clusters contribute equally to the purpose) in order to compare the four PDOs.

6. Discussion

ANP is a comprehensive approach to decision making that helps to organise and structure priorities when multiple criteria and stakeholders are involved. This method has proven to be useful when modelling a broad range of functions generated by olive oil under PDO and using several farming systems. It allows designing a network that gathers the relationships and influences among all the elements when interdependences exist.

The criteria selected were private goods and the most valuable public goods that olive oil groves are able to generate, according to the experts. We have found that priorities of clusters and criteria are similar in all PDOs, despite the different agronomic, economic, environmental and social features. The order and weightings for clusters are economic (40%), sociocultural (36%) and environmental (24%). This result agrees with Gómez-Limón and Arriaza (2013) on the social demand for rural multifunctionality but contrasts with Carmona-Torres et al. (2014), who assert that farmers neglect to a certain extent the social impact and, even more, the environmental impact of their activity. If experts are to evaluate, they give more importance to both social and environmental criteria, as society does, whereas farmers are not rewarded for producing public goods and are, hence, not concerned. Nevertheless, this comparison has to be explained because, under the sociocultural cluster, we have a criterion, *governance*, ranked in the first position, which has not been considered in other studies.

Governance is the criteria to introduce institutions in the ANP model, not only formal institutions like Regulatory Councils of PDOs or agricultural associations and bodies but also informal institutions like traditions, habits and customs. *Governance* has not been used in previous studies and has proved to be the most important element to achieve olive oil grove sustainability. In fact, previous papers on this subject have been more interested in analysing the influence of farming systems or farmer decisions on criteria than in ranking these criteria according to their capability to reach PDO sustainability. Only Parra-López et al. (2008), using AHP, rank groups of criteria and criteria within each group to find out which farming system (organic, integrated or conventional) performs the best. In our work, criteria are important as long as they contribute to sustainability, and our first aim has been to rank them.

Apart from *governance*, *quality* and *commercialization* were the more valued criteria. This corresponds well with olive oil under PDO due to higher quality, compared to regular olive oil, and more difficulty selling it because of the higher prices expected.

As regards farming systems contributing to maximize all criteria, our results show that organic farming is the best for all groups of functions, followed by integrated and, then, conventional farming, except for Estepa. In the case of environmental criteria, abandonment is preferred to conventional farming. These results are similar to a certain extent to the results of Parra-López et al. (2008) found for Andalusian olive groves as a whole, taking into account that they do not consider the alternative of abandoning olive groves.

The above comparisons have to be put in context due to the fact that the clusters built in the mentioned works do not contain the same criteria as in our study. Furthermore, in our work, we argue that all criteria contribute with their own weighting to sustainability and have to be achieved through a proper farming system combination that is different in each PDO. There is not a single farming system able to meet the optimum combination of criteria and, hence, able to assure sustainability.

7. Conclusions

Bearing in mind the objective of maximizing the sustainability of olive oil PDOs through different farming systems, the following conclusions are drawn. The three most important criteria are *governance* (the relationship between social agents and institutions that promotes innovation and entrepreneurship), the guarantee of final product *quality* and the collaboration of all agents to establish good institutions and networks for *commercialization*. These results remain steady even when modifying certain methodological hypotheses regarding the number of clusters or their relative weightings. These changes do not affect the results.

Our results confirm that positive externalities in agricultural activity are very valuable for society and contribute to sustainability in rural areas. We have found that the quantities of these externalities produced can be maximized by using the best combination of different farming systems. Most importantly, institutions are able to create changes in local farming systems to achieve their optimum combination. Local institutions – so called *governance* – do so by improving relationships among stakeholders, encouraging innovation and entrepreneurship, and European institutions do so by paying farmers for the non-market benefits – externalities – generated by olive groves. Moreover, public aid for olive groves is needed for non-financially profitable farms, which are respectful of the environment, and even for olive crop abandonment because of the externalities they produce.

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