Assessing the impact of agri-environmental schemes on the eco-efficiency of rain-fed agriculture

M. Beltrán-Esteve[1],*, J. A. Gómez-Limón[2] and A. J. Picazo-Tadeo[1]

[1] Departamento de Economía Aplicada II. Universidad de Valencia. Campus de Tarongers.
46022, Valencia. Spain
[2] Departamento de Economía, Sociología y Política Agrarias. Universidad de Córdoba.
Puerta Nueva s/n. 14071, Córdoba. Spain

Abstract

This paper analyses the impact of the Agri-environmental Extensification Scheme for the Protection of Flora and Fauna (F&F Scheme) on the eco-efficiency of a sample of dryland farms in the Spanish region of Castile and Leon. Using *Data Envelopment Analysis* (DEA) and the so-called *program decomposition approach* to efficiency measurement, we explore whether or not the production technology of the farms included in the F&F Scheme is more eco-efficient than the technology used by farms that are not included in the Scheme. The results obtained confirm the foregoing hypothesis, providing evidence that environmental pressures could be reduced if all farms adopted the F&F Scheme technology. Furthermore, shadow prices are used to assess the monetary value of the potential reduction in environmental pressures that farms could achieve by adopting the F&F Scheme. The results show that the average opportunity cost of the decrease in environmental pressures (€55.65 ha^{-1}) is similar to the compensation received by farms included in the F&F Scheme. Nevertheless, bearing in mind the great diversity of farms, we recommend agricultural policymakers to use an auction system to award such environmental contracts.

Additional key words: data envelopment analysis (DEA); economic-ecological efficiency; shadow prices; agrienvironmental policy; Spain.

Resumen

Valoración del impacto de los programas agroambientales sobre la eco-eficiencia de la agricultura de secano

Este artículo analiza el impacto del Programa Agroambiental de Extensificación para la Protección de la Flora y Fauna (F&F Scheme) sobre la eco-eficiencia de una muestra de explotaciones agrarias de secano de Castilla León. Utilizando técnicas de *Análisis de la Envolvente de Datos* (DEA) y la aproximación a la medición de la eficiencia conocida como *descomposición por programas,* se estudia si la tecnología de producción de las explotaciones que adoptan el programa agroambiental es más eco-eficiente que la tecnología utilizada por aquellas explotaciones que no están acogidas al mismo. Los resultados obtenidos confirman esta hipótesis, evidenciando la posibilidad de reducir las presiones ambientales si todas las explotaciones adoptaran la tecnología del programa agroambiental. Asimismo, se utilizan los precios sombra de las presiones para obtener un valor monetario de la reducción potencial que podría alcanzarse adoptando la tecnología F&F. Los resultados muestran que, en promedio, el coste de oportunidad de reducir las presiones (55,65 € ha^{-1}) es similar a la compensación que reciben las explotaciones por participar en el Programa F&F. En cualquier caso, habida cuenta de la gran variabilidad existente entre explotaciones, se aconseja adjudicar este contrato medioambiental mediante un sistema de licitaciones.

Palabras clave: análisis envolvente de datos (DEA); eficiencia económica-ecológica; precios sombra; política agroambiental; España.

Abbreviations used: CAP (common agricultural policy); CRS (constant returns to scale); DEA (data envelopment analysis); DMU (decision making unit); F&F Scheme (Agri-environmental Extensification Scheme for the Protection of Flora and Fauna); PGT (pressure generating technology); VRS (variable returns to scale).

Introduction

Economic activities affect the environment through the use they make of natural resources, the waste materials they generate and occasionally through the environmental services they provide and the improvements they make in the habitat. This is the case of farms (Hodge, 2000; MEA, 2005), which have become the object of growing concern since the 1990s regarding their impact on the environment. On the one hand, society is somewhat alarmed by the pollution stemming from the excessive use of fertilisers and pesticides and also by the erosion of basic natural resources (soil and water) caused by intensive agriculture. On the other hand, society is equally concerned about the threat of this activity being abandoned in high natural value systems due to not being profitable, insofar as this could reduce landscape diversity and the biodiversity associated with traditional farming (Cooper *et al.*, 2009).

The concept of *sustainable agriculture* (Hansen, 1996) gives expression to this concern over the relationship between farm activity and the environment. The notion of economic-ecological efficiency, commonly known as eco-efficiency, emerged in the 1990s as a practical approach to the more encompassing concept of sustainability (Schaltegger, 1996). Generally speaking, eco-efficiency refers to the ability of firms, industries or economies to produce more goods and services with fewer impacts on the environment and less consumption of natural resources. Eco-efficiency assessment is therefore a valid instrument to analyse farm sustainability, in that it relates economic value to farming activity and its impact on the environment (Huppes & Ishikawa, 2005).

At European Union level, the relationships between agriculture and the environment are managed by the public sector through Common Agricultural Policy (CAP). The goals of this policy include ensuring that farming practices do not harm the environment and preserve the natural assets of rural areas. CAP relies on two main mechanisms to accomplish this goal (Latacz-Lohmann & Hodge, 2003). The first is *cross-compliance*, which requires farmers to comply with the Good Agricultural and Environmental Condition (GAEC) standards in order to be eligible to receive direct payments on farm income (Alliance Environnement, 2007). The second instrument is agri-environmental schemes, which are contracts signed voluntarily by farmers through which they pledge to supply environmental services above and beyond those established by cross-compliance standards. In exchange, farmers receive monetary payments equiv-

alent to the loss of earnings (income that farmers no longer earn as a result of performing the environmental services agreed previously) and extra costs incurred as a result of performing these activities (EC, 2005 and 2006).

In this scenario, the objective of this paper is to analyse the impact of CAP agri-environmental schemes on the eco-efficiency of European farms. More specifically, we study the Agri-environmental Extensification Scheme for the Protection of Flora and Fauna (F&F Scheme henceforth) implemented in the Spanish region of Castile and Leon. This agri-environmental measure is part of the 2000-2006 Rural Development Program of the Castile and Leon region and is implemented by the Ministerial Order of 11 July, 2002 issued by the Regional Department of Agriculture and Livestock (see MARM, 2008 for an intermediate institutional assessment of the results of this scheme). Its purpose is to help maintain extensive dryland farming systems and encourage practices that improve and diversify the habitat to provide food and shelter for the steppe bird species typically found in these high natural value systems. In this sense, by calculating the level of eco-efficiency of the farms included in the agri-environmental F&F Scheme and those which are not, we seek to analyse simultaneously the economic impact on farm income and the environmental effects associated to the production technologies used by these farms.

The main interest of this research is that the results can provide agricultural policymakers with relevant information to justify the F&F Scheme and also to guide its implementation in relation to issues such as the necessary size of environmental payments or the contract awarding system, among others. The paper aims to answer the following key questions: a) are the farms included in the F&F Scheme more eco-efficient than those that are not?; b) if this is the case, is the F&F Scheme production technology more eco-efficient?; c) how much money would compensate the opportunity costs of farms that wish to become part of the Scheme? The answers to these questions fill a gap in the knowledge required to improve agricultural governance through agri-environmental schemes.

Methodology and dataset

Assessing eco-efficiency with data envelopment analysis

The concept of eco-efficiency can be formalised by way of a ratio between indicators of economic and

ecological performance. In order to assess the eco-efficiency of a farm or a group of farms, we must compare their performance with the possibilities that available technology offers. As technology is unknown, we must estimate it using observed data and either parametric or non-parametric techniques. Introduced by Charnes *et al.* (1978), Data Envelopment Analysis (DEA) is a non-parametric efficiency analysis technique which, on the grounds of basic assumptions regarding production technology, uses mathematical programming to assess the relative performance of a series of decision making units (DMUs), comparing each to the best observed practices.

Let us assume that we observe a sample of k = 1, …, K farms, each of which obtains value added v_k in their production process, while at the same time generating a set of n = 1, …, N harmful environmental pressures, represented by the variables p_{nk}. Following Kuosmanen & Kortelainen (2005) and Picazo-Tadeo *et al.* (2011), the *Pressure Generating Technology* (PGT), which represents the possible combinations of value added and environmental pressures, is defined as:

$$PGT = \left[(v, p) \in R_+^{1+N} \,\middle|\, \text{value added v can be generated with pressures p} \right] \quad [1]$$

After establishing the technology of reference, the eco-efficiency of a farm k^o can be formalised as the ratio between its value added and the aggregate environmental pressure generated by its production activity:

$$\text{Eco-efficiency}_{k^o} = \frac{\text{Added value}_{k^o}}{\text{Aggregate environmental pressure}_{k^o}} =$$
$$= \frac{v_{k^o}}{P(p_{nk^o})} = \frac{v_{k^o}}{\sum_{n=1}^{N} w_{nk^o} p_{nk^o}} \quad [2]$$

where P is an aggregation function that allows to compute the aggregated environmental pressure as a weighted average of the individual pressures that farm k^o exerts, w_{nk^o} being the weighting or relative importance assigned to each pressure.

Some studies weight environmental pressures on the basis of exogenous information such as expert opinions (Mauchline *et al.*, 2012), while others use more arbitrary criteria, such as assigning the same weights to all pressures. The DEA techniques used in this research to assess eco-efficiency have the advantage of generating the weightings for environmental pressures endogenously. As a result, no prior judgements or assessments are required. The weighting or *shadow price* assigned to each environmental pressure varies from one farm to another and is calculated in such a way that it rates each farm in the most favourable light in relation to all the other farms in the sample, when those same weightings are used.

More specifically, we use a linear form of what is known in the DEA literature as a *primal problem* (Cooper *et al.*, 2007) to determine the shadow prices of environmental pressures (variables w_{nk^o}) that result in the best possible ranking of farm k^o. Formally, this is written as follows (see Kuosmanen & Kortelainen, 2005):

$$\text{Minimize}_{w_{nk^o}} \ \text{Eco-efficiency}_{k^o}^{-1} = \sum_{n=1}^{N} w_{nk^o} \frac{p_{nk^o}}{v_{k^o}}$$

subject to: [3]

$$\sum_{n=1}^{N} w_{nk^o} \frac{p_{nk}}{v_k} \geq 1 \qquad k = 1, ..., K \qquad (i)$$

$$w_{nk^o} \geq 0 \qquad n = 1, ..., N \qquad (ii)$$

Furthermore, eco-efficiency scores are obtained from the so-called *dual problem*, which in formal terms is expressed as follows:

$$\text{Minimize}_{\theta_{k^o}, \lambda_k} \ \text{Eco-efficiency}_{k^o} = \theta_{k^o}$$

subject to:

$$v_{k^o} \leq \sum_{k=1}^{K} \lambda_k v_k \qquad\qquad (i) \quad [4]$$

$$\theta_{k^o} p_{nk^o} \geq \sum_{k=1}^{K} \lambda_k p_{nk} \qquad n = 1, ..., N \qquad (ii)$$

$$\lambda_k \geq 0 \qquad\qquad k = 1, ..., K \qquad (iii)$$

In this case, the λ_k intensity variables represent the relative weight of each farm in the sample in the construction of the eco-efficient frontier that production unit k^o will be compared to. The solution to program [4] measures the minimum proportion of observed environmental pressures that farm k^o would have to exert to obtain its value added and can take values between zero and one, the latter denoting eco-efficiency. For example, a score of this parameter equal to 0.8 would indicate that the farm could maintain its value added while only generating 80% of its current environmental pressures.

It is worth pointing out that constant returns to scale (CRS) are imposed in program [4]. Farm size is a key

variable determining farms' economic performance because economies of scale are relevant in agricultural production. Thus, when analysing economic/ technical efficiency in agriculture at farm level, variable returns to scale (VRS) are frequently assumed. However, farm size is not a relevant issue from an ecological perspective and agriculture is commonly considered a CRS activity; in other words, what really matters for ecosystems are agricultural practices rather than how they are allocated across individual farms (Gómez-Limón *et al.*, 2012).[1] Eco-efficiency involves analysing the economic and ecological performance of farming activities simultaneously. As a result, both of the abovementioned considerations should be taken into account. However, as the current *state-of-the-art* provides no further hints on this choice (Lozano *et al.*, 2009), we have decided in favour of CRS as the most common assumption in the literature (see Kuosmanen & Kortelainen, 2005).

After achieving the radial or proportional reduction in all the environmental pressures necessary to become eco-efficient, it may still be possible to achieve specific reductions in some of them. These additional decreases or slacks can be obtained by way of the following mathematical program:

$$\text{Maximize}_{s_{k^o}^v, s_{nk^o}^p, \lambda_k} \ S_{k^o} = s_{k^o}^v + \sum_{n=1}^{N} s_{nk^o}^p$$

subject to:

$$v_{k^o} + s_{k^o}^v = \sum_{k=1}^{K} \lambda_k v_k \qquad\qquad\text{(i)}$$

$$\theta_{k^o}^* p_{nk^o} - s_{nk^o}^p = \sum_{k=1}^{K} \lambda_k p_{nk} \quad n = 1, ..., N \qquad\text{(ii)}$$

[5]

$$s_{k^o}^v, s_{nk^o}^p \geq 0 \qquad\qquad v = 1 \text{ and } n = 1, ..., N \quad\text{(iii)}$$

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

where $\theta_{k^o}^*$ is the solution obtained from [4] for farm k^o, $s_{k^o}^v$ the value added shortfall and $s_{nk^o}^p$ the excess or slack in environmental pressure p.

In keeping with Picazo-Tadeo *et al.* (2011), the eco-efficiency score obtained from expression [4] and the slacks calculated using program [5] can be combined to obtain specific eco-efficiency indicators for each

environmental pressure.[2] Formally, these indicators would be:

$$\text{Pressure specific eco-efficiency}_{p_{nk^o}} = \theta_{k^o}^* - \frac{s_{nk^o}^p}{p_{nk^o}} \qquad\text{[6]}$$

The pressure specific eco-efficiency indicators are by construction equal to or lower than the radial or proportional indicators and are interpreted in the same way. For example, a score of 0.75 for environmental pressure n would indicate that the farm could produce the same value added while only generating 75% of the pressure in question. By including information on slacks when computing specific eco-efficiency measures, we can assess the full potential of farms to reduce environmental pressures while maintaining their value added.

Managerial and program eco-efficiency

The methodology for assessing program efficiency was initially proposed by Charnes *et al.* (1981) in one of the first empirical applications of DEA. It was later further developed by several authors, including Silva & Thanassoulis (2001) and O'Donnell *et al.* (2008). Essentially, this approach to measuring efficiency suggests that different groups or programs within the same economic activity can have access to different production technologies. Charnes *et al.* (1981) distinguish between *managerial or intra-group efficiency*, which assesses performance when firms are compared to the best observed practices within the group or program they belong to, and *program or inter-group efficiency*, which identifies differences in technology between groups or programs.

As suggested by Gómez-Limón *et al.* (2012), this methodological approach can also be used to analyse eco-efficiency, making it entirely suitable for the purpose of our research. In our case study, we aim to determine whether the possible difference between the eco-efficiency of farms included in the F&F Scheme and the eco-efficiency of those that are not is due to the use of different production technologies (differ-

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[1] By way of example, for an ecosystem there is no difference between the discharge of 10 doses of pesticides per hectare by a single farmer managing 100 ha or by 20 farmers operating with 5 ha each.
[2] Recently, Picazo-Tadeo *et al.* (2012) have also proposed the use of directional distance functions to compute scores of eco-efficiency at the specific environmental pressure level.

ences in program eco-efficiency) or, perhaps, to an abnormal concentration of good/bad managers in a given program (differences in managerial eco-efficiency). This analysis is particularly important when it comes to assessing agri-environmental policy, as it makes it possible to ascertain how effective measures or specific schemes are in terms of their impact on production technologies.

Before addressing the mathematical formulas necessary to assess eco-efficiency, providing graphic support for the economic intuition of this concept is highly illustrative. Let us consider a production process that generates value added v and two environmental pressures p_1 and p_2. Furthermore, there are two types of farms that carry out this type of productive activity, that is, those included in the F&F Scheme and those which are not. Drawing a parallel with conventional production theory, technology can be represented by the set of pressure requirements necessary to produce a certain value added. The lower envelope of this set of pressure requirements would be the iso-value curve that determines the eco-efficient technological frontier.

Fig. 1 assumes we observe a set of farms participating in the F&F Scheme, indicated by crosses, and another set of farms that are not part $\theta$of that scheme indicated by dots. The technological frontier of each program or group is represented by an iso-value curve and constructed using the most efficient observations within that group. Likewise, for the sake of simplicity, we assume in this illustrative example that the joint technological frontier, that is, considering all the ob-
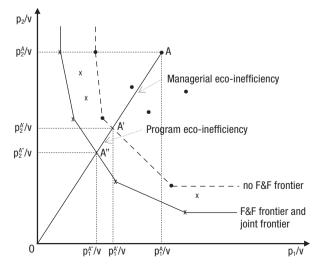
servations regardless of the group they belong to, coincides with the frontier of the F&F Scheme, as the production technology of this group is supposedly more eco-efficient.

Now let us consider a farm A, which is not part of the F&F Scheme. In the Fig. 1 we can see that, when compared to the joint technological frontier, production unit A could achieve the same value added while generating significantly less environmental pressures, represented by A''. However, two different factors can cause this eco-inefficiency, namely poor business management and the use of eco-inefficient technology. In the first place, farm A fails to make eco-efficient use of the technology available within its group, incurring in managerial inefficiency as a result. If the technology available to the no F&F Scheme were used efficiently, farm A would be able to reduce its environmental pressures to point A'. In addition, and in the second place, farm A could continue to reduce its environmental pressures from point A' to point A'' by using the most eco-efficient production technology in F&F Scheme. The distance between the two technological frontiers represents the eco-inefficiency caused by using eco-inefficient technology or program eco-inefficiency.

Formally, the decomposition of aggregate eco-efficiency into managerial and program eco-efficiency can be written as:

$$\text{Eco-efficiency} =$$
$$= \text{Managerial eco-efficiency} \cdot \text{Program eco-efficiency, or} \quad [7]$$
$$OA''/OA = (OA'/OA) \cdot (OA''/OA')$$

Our main interest in this decomposition, however, is not to assess eco-efficiency at farm level, but rather to assess the eco-efficiency difference between programs, that is, the distance between the eco-efficient frontiers of the two groups of farms under consideration. In order to do so, Charnes *et al.* (1981) proposed a four-stage process, which is described below. In the first stage, the farms in the sample must be separated into two groups corresponding to the programs being analysed, that is, the F&F Scheme, which we assume has K_1 farms, and the no F&F Scheme with $K_2 = K - K_1$ farms. Once the groups have been defined, mathematical program [4] must be used to compare every farm in each group (K_i, i = 1, 2) to the farms that display the best performance within that same group. The result for a farm k^o that belongs to group K_i is a measure of its managerial or intra-program eco-efficiency, which we will refer to as $\theta_{k^o}^{*\,\text{Managerial } K_i}$.

Figure 1. Managerial and program eco-efficiency.

In the second place, we must calculate the eco-efficient levels of the environmental pressures of each farm within its own group, which is achieved by projecting the eco-inefficient farms onto their respective technological frontiers. Formally, for farm k^o:

$$p_{nk^o}^{\text{Eco-efficient } K_i} = \theta_{k^o}^{* \text{ Managerial } K_i} \cdot p_{nk^o} \qquad k^o \in K_i \text{ and } i = 1,2 \quad [8]$$

The environmental pressure values obtained by applying expression [8] to all the units in the sample would make up two groups of *virtual* farms that make eco-efficient use of their own production technologies, that is, the technologies in the F&F and no F&F programs respectively. As a result, we will have eliminated the influence of a possible concentration of good/bad managers in either of the two programs or groups of farms.

The third step consists of grouping all the virtual farms obtained in the previous stage into one sample and, once again using program [4], calculating the eco-efficiency of each farm in regard to a joint frontier. The solution to the program, which in this case we will refer to as $\theta_{k^o}^{* \text{ Program}}$, provides an estimation of the program or inter-group eco-efficiency of farm k^o, which is equivalent to the distance between the frontier of its own group and the joint technological frontier. If the F&F Scheme were more eco-efficient than the no F&F Scheme, the eco-efficiency scores of the first group of farms can be expected to be close to one, while the scores recorded by the second group would be lower than one.

However, the program eco-efficiency scores of the individual farms are difficult to interpret. The real point of interest is to ascertain whether or not there are statistically significant differences between the eco-efficient frontiers of the two programs or groups. In order to do so, the fourth and final stage involves performing a statistical test to determine the significance of the differences in average program efficiency between the two groups of farms. One of the most frequently used is the Mann-Whitney rank-sum test (Grosskopf & Valdmanis, 1987; Brockett & Golany, 1996).

Calculating shadow prices for environmental pressures

The results obtained from the program efficiency analysis make it possible to assess whether or not the production technology of one program is more eco-efficient than the other. However, they also allow us to quantify the decrease in environmental pressures that could be achieved if the farms in the less eco-efficient program adopted the technology of the most eco-efficient program. Assuming the least eco-efficient program is that which includes the farms that are not a part of the F&F Scheme, once managerial eco-inefficiency has been cleaned up, the additional potential decrease in pressures of a farm k^o that decided to adopt the F&F Scheme would be:

$$p_{nk^o}^{\text{Reduction}} = \left(1 - \theta_{k^o}^{* \text{ Program}}\right) \cdot p_{nk^o}^{\text{Eco-efficient } K_i} \qquad k^o \in K_i \text{ and } i = \text{no F\&F} \quad [9]$$

Expression [9] therefore assesses the potential reduction in each of the environmental pressures that, after adjusting to account for managerial eco-inefficiency, farm k^o can achieve by adopting the best overall practices, that is, by implementing the production technology used by the farms included in the F&F Scheme. We would therefore obtain a valuation of the impact of the F&F Scheme in terms of the *physical* reduction in each pressure.

In order to determine whether the farmers participating in the environmental scheme receive sufficient payments to compensate for applying more environmentally friendly production practices, it is necessary to value the physical reduction in environmental pressures in monetary terms. The problem is that such pressures do not have prices due to there being no market. However, one alternative is to value the reduction in pressures on the environment using shadow prices.

DEA techniques allow us to estimate the shadow prices of the environmental pressures generated by each farm from program [3] (Färe *et al.*, 2005, 2006; Misra & Kant, 2007; Leleu & Briec, 2009; Arandia & Aldanondo-Ochoa, 2011). The variables w_{nk} obtained as the solution to this primal program measure the impact of a change in each of the technological restrictions on eco-efficiency. Consequently, they can be used to create a shadow price for each environmental pressure, together with the value of their marginal product. Following Oude-Lansink & Silva (2004), the marginal product of environmental pressure p_n in farm k^o is determined as the change in value added stemming from a marginal change in the environmental pressure. In formal terms:

$$\text{Marginal product}_{p_{nk^o}} = \frac{\partial v_{k^o}}{\partial p_{nk^o}} = -\frac{\partial \theta_{k^o} / \partial p_{nk^o}}{\partial \theta_{k^o} / \partial v_{k^o}} \quad [10]$$

The variables involved in the numerator and denominator on the right hand side of expression [10] are obtained from the dual variables in model [3] associated to the restrictions of each environmental pressure and the restriction of value added, respectively. The shadow price of each environmental pressure is equal to the value of its marginal product. As a result, if we have the price of the product obtained, we are in a position to assign a monetary value to the environmental pressure, such as:

$$\text{Shadow price}_{p_{nk^o}} = \text{Price}_v \cdot \text{Marginal product}_{p_{nk^o}} \quad [11]$$

In our case, the product obtained is value added. This variable is expressed in monetary terms, so its price is the monetary unit. Therefore, the shadow price of each environmental pressure in each farm is equivalent to its marginal product. When a farm performs eco-inefficiently in relation to a given environmental pressure, the *opportunity cost* of improving its performance or shadow price will be relatively low. However, when a farm already exerts very little pressure on the environment, the opportunity cost of further reducing pressure will be relatively high (Reig-Martinez *et al.*, 2001; Arandia & Aldanondo-Ochoa, 2011).

Finally, the opportunity cost in terms of lost value added that each farm not included in the F&F Scheme will incur as a result of adopting it can be calculated using the shadow prices of the various environmental pressures, expression [11], and their physical reduction calculated according to expression [9]. In formal terms:

$$\text{Opportunity cost}_{k^o} = \sum_{n=1}^{N} \text{Shadow price}_{p_{nk^o}} \cdot p_{nk^o}^{Reduction} \quad [12]$$

$$k^o \in K_i \text{ and } i = \text{no F\&F}$$

Expression [12] therefore provides an estimation of the value added lost as a result of reducing the environmental pressures associated to adopting the technology of the most eco-efficient program, the F&F Scheme. This would be the lost value added that agri-environmental payments should compensate in order to encourage producers to use the most eco-efficient production technology.

It is worth mentioning that in the computation of the opportunity cost it is implicitly assumed that *all* existing damaging environmental pressures are considered in the analysis; furthermore, shadow prices are evaluated at the projections on the program eco-efficient frontier. In any case, expression [12] must be considered an accurate enough way to estimate the opportunity cost resulting from the implementation of a more environmentally friendly production technology if the most important pressures are taken into account and the reductions considered in each environmental pressure are not too large.

Agricultural system under study and sample of farms

The empirical analysis performed in this research is based on information from a sample of farms that operate in four agricultural counties (Cerrato, Campos, Saldaña-Valdavia and Boedo-Ojeda) in the region of Castile and Leon in the northwest of Spain. All these neighbouring counties are included in a single agricultural system known as *Rain-fed agriculture in medium-altitude countryside* (MAPA, 2004). This system is characterised by a continental climate, large open plains and a production dominated by arable dryland crops, mainly winter cereals (barley, wheat, oats and rye), although other crops such us alfalfa, sunflowers, peas or vetch are also cultivated.

The suitability of this farming system as a case study can be justified by a number of reasons. Firstly, its technical characteristics (ecological –soil and climate–, economic, social and political homogeneity), which ensure that the sample of farms chosen are sufficiently uniform from a technological point of view; secondly, the ready availability of information (*i.e.*, the ability to survey a sample of farms that would be sufficiently large to enable us to perform quantitative analyses); and thirdly, the existence of a relatively widespread agri-environmental scheme (F&F Scheme). Furthermore, this case study is also interesting for practical reasons, as this farming and rural area is currently under threat due to a lack of profitability and, therefore, the social and environmental roles of farms are actually more important in relative terms than their mere economic function (Kallas *et al.*, 2007). It is worth quoting here the paper by Barreiro-Hurlé *et al.* (2009), that analyses the relationship between technical efficiency and farmers' enrolment in an agri-environmental scheme called 'introduction of nitrogen fixing crops in dry-land areas', also in another extensive cereal farming system in Spain.

The sample information on the farms analysed was obtained in the months of March and April, 2008 by

quota sampling the population as a whole (according to the last Agricultural Census, dating from 1999, there are 7,276 farms in the area under study) by farming area and producer affiliation to the various Professional Agricultural Organisations. The information was gathered using a questionnaire that focused on the structural features of the farm, the socio-demographic characteristics of farm owners, the activities and agricultural production techniques used and the type of subsidies and payments received under the CAP. The information refers to the 2006-07 farming season in all cases. A total of 241 farms completed the questionnaire satisfactorily, of which 78 are included in the F&F Scheme, while the remaining 163 receive no agri-environmental payments whatsoever.

The primary information from the survey has been complemented by secondary information necessary to obtain the economic and environmental indicators used in the analysis.

Economic and environmental indicators

Value added per hectare of cultivated land is used to measure the economic performance of farms. This indicator includes the income earned by the primary production factors, labour, capital and land. This variable has been obtained for each farm as sales and the subsidies and agri-environmental payments producers receive, less the intermediate costs of the production process:

$$v_k = \frac{\left(Sales_k + Subsidies_k\right) - Intermediate\ costs_k}{Land_k} \quad [13]$$

The variable *Sales_k* represents the sales of farm k and has been obtained as the sum of income from the various farm produce obtained. The subsidies and payments received by the farm, *Subsidies_k*, are added to this income, as farmers consider these payments to be another source of income when making decisions about what to produce and how to go about doing so. These payments include coupled subsidies (payments for surface area depending on crops) and agri-environmental payments, including those from the F&F Scheme in the case of the farms included in that scheme. The variable *Intermediate costs_k* includes the cost of using seeds, nitrogen fertilisers and phosphates, pesticides and energy. Finally, *Land_k* represents the total surface area of the farm in hectares.

As regards the environmental performance of the farms in the sample, the five most significant environmental pressures have been considered, namely pressure on biodiversity, nitrogen balance, phosphorous balance, pesticide risk and finally the energy ratio.

The *pressure on biodiversity*, variable p_1, is intended to capture the environmental pressure that a farm can exert through highly specialised production, as tending to grow only one type of crop (monoculture) reduces the biodiversity of the wild flora and fauna. This variable was obtained using Shannon's Diversity Index (SHDI), which is calculated taking into account the number of varieties of crops produced and also distribution regularity. In formal terms:

$$Biodiversity\ pressure_k = p_{1k} = \frac{1}{e^{SHDI_k}}$$

$$where\ SHDI_k = -\sum_{c=1}^{C}\left[s_{ck} \cdot \ln\left(s_{ck}\right)\right],\ and\ s_{ck} = \frac{Land_{ck}}{Land_k} \quad [14]$$

In addition, *Land_{ck}* represents the number of hectares that farm k devotes to crop c (c = 1, … C), such that s_{ck} is the proportion of total farmland devoted to crop c.

Pressure on diversity takes a maximum value of one if farms produce only one crop, but this value decreases and tends to zero as the number of crops that farms produce increases and farmland is more regularly shared among them. Insofar as greater specialisation has a negative effect on the wild flora and fauna, the higher the value recorded by the indicator, the more environmental pressure the farm exerts.

The *Nitrogen balance*, variable p_2, is the second indicator of environmental pressure. This variable measures the impact that agriculture can exert on the environment due to the excessive use of nitrogen as a fertiliser (water pollution). This pressure is calculated for farm k as the difference between the nitrogen contained in the inputs (fertilisers) used for every crop c (*Nitrogen input_{ck}*) and the amount of nitrogen extracted when crop *c* is harvested (*Nitrogen output_{ck}*). Formally:

$$Nitrogen\ balance_k = p_{2k} =$$
$$= \sum_{c=1}^{C}\left(Nitrogen\ input_{ck} - Nitrogen\ output_{ck}\right) \cdot s_{ck} \quad [15]$$

This environmental pressure indicates the kilograms of nitrogen per hectare that farm k released to the environment every year. Logically, the higher the nitrogen balance, the more environmental pressure.

Similar to the previous indicator, the *Phosphorus balance*, pressure p_3, captures the difference between the phosphorous used for fertilising every crop c (*Phosphorus input$_{ck}$*) and the phosphorous contained in the products harvested (*Phosphorus output$_{ck}$*). In formal terms:

$$\text{Phosphorus balance}_k = p_{3k} =$$
$$= \sum_{c=1}^{C} \left(\text{Phosphorus input}_{ck} - \text{Phosphorus output}_{ck} \right) \cdot s_{ck} \quad [16]$$

This pressure indicates the kilograms of phosphorous per hectare and year that farm k dumps into the environment. As in the previous case, the higher the phosphorous balance, the more environmental pressure.

Pressure *Pesticide risk,* variable p_4, measures the potential biocide capacity of the active principles in pesticides used in farm processes. This indicator has been estimated by adding the potential lethality of all phytosanitary products used for agricultural production in regard to live organisms. The specific formula used to obtain this pressure from farm k is:

$$\text{Pesticide risk}_k = p_{4k} = \quad [17]$$
$$1{,}000 \cdot \sum_{c=1}^{C} \left(\sum_{m=1}^{M} \frac{1{,}000 \cdot \text{Commercial product}_{mck} \cdot \text{Active principle concentration}_m}{\text{Lethal dose 50}_m} \right) \cdot s_{ck}$$

where *Commercial product$_{mck}$* is the quantity of commercial product m applied per hectare and year to grow crop c (in kg ha^{-1}), *Active principle concentration$_m$* is the concentration of active principles in product m (in %) and *Lethal dose 50$_m$* (in mg of product m kg^{-1} of rat) is the total lethal dose 50% (amount of the active substance that would kill half the animals, usually rats, in a laboratory experiment).

The pesticide risk accounts for the biocide potential of the pesticides used by farm k (in g of rat ha^{-1} yr^{-1}). The higher the value of this indicator, the more pressure the farm exerts on the environment.

Finally, the *Energy ratio*, pressure p_5, compares the energy contained in inputs (seeds, fertilisers, etc.) and in the activities (machinery, fuel, etc.) required to grow each crop c (*Energy inputs$_c$*), with the energy contained in the output or harvested products (*Energy output$_c$*). In the case of farm k, it is calculated as follows:

$$\text{Energy ratio}_k = p_{5k} = \sum_{c=1}^{C} \left(\frac{\text{Energy inputs}_{ck}}{\text{Energy output}_{ck}} \right) \cdot s_{ck} \quad [18]$$

This indicator measures the energy consumed per kilocalorie produced. If this indicator records a high value, a farm must consume more energy in order to obtain a kilocalorie in the agricultural goods that farm k produces. Obviously, the higher the energy ratio is, the greater the pressure the farm exerts on the environment.

Table 1 presents the main descriptive statistics of all these variables for the whole sample of farms and separately for each of the groups considered. This table also includes the results of a t-test for the statistical significance of averages across farms included and not included in the F&F Scheme. Furthermore, Table 2 provides detailed information about the area devoted to different crops in each case. Although crop mixes are similar, statistical differences can be observed between both groups of farms. Farms covered by the F&F Scheme have a higher proportion of oilseeds and protein crops at the expense of traditional grains. These differences reflect the requirement in the F&F contract to allocate at least 15% of farm surface area to these more environmentally friendly crops.

Results

Eco-efficiency assessment

Using the variables described in the previous section, we have calculated eco-efficiency scores for the 241 farms in the sample by solving program [4] for each of them. In order to do so, we used the joint sample of farms to construct the technological frontier. The results are presented in Table 3.

The average eco-efficiency score for the sample of farms as a whole was 0.62, indicating that, on average, they could obtain the same value added while at the same time reducing the pressures their productive activity exerts on the environment by 38%. In other words, the economic-ecological management of the farms analysed is markedly inefficient. Moving on, the farms included in the F&F Scheme recorded an average eco-efficiency score of 0.72, while those not included registered an average score of 0.57. Therefore, while the farms participating in the F&F Scheme could reduce the environmental pressures they generate by 28%, those not participating in the scheme could potentially reduce the pressure they exert on the environment by 43%, while always maintaining their level of value added. According to the results of the Mann-Whitney

Table 1. Sample description

	All farms (241)			Farms included in the F&F Scheme (78)			Farms not included in the F&F Scheme (163)			t-test[a] (*p*-value)
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	
Output (€ ha⁻¹ yr⁻¹)	508.4	68.4	785.7-262.8	515.7	72.5	785.7-262.8	504.9	66.3	670.2-272.1	–1.16 (0.247)
Sales	461.6	66.3	721.4-230.2	446.1	69.2	721.4-230.2	469.0	63.8	650.7-258.1	2.53 (0.012)
Coupled subsidies	35.1	5.7	39.0-3.3	33.3	6.1	39.0-7.1	35.9	5.3	39.0-3.3	3.42 (0.001)
F&F Scheme subsidies	11.8	18.1	55.9-0.0	36.4	10.8	55.9-11.2	0.0	0.0	0.0-0.0	–43.20 (0.000)
Inputs (€ ha⁻¹ yr⁻¹)	209.2	46.3	346.0-115.9	198.9	43.9	322.9-141.9	214.1	46.7	346.0-115.9	2.41 (0.017)
Seeds	54.2	12.7	129.1-26.6	52.3	10.8	90.0-26.6	55.1	13.5	129.1-31.2	1.61 (0.109)
Nitrogen	67.1	43.1	217.6-0.7	62.3	39.2	181.5-23.3	69.4	44.7	217.6-0.7	1.20 (0.231)
Phosphorus	25.8	10.1	84.0-0.0	24.4	9.3	62.5-12.1	26.5	10.4	84.0-0.0	1.51 (0.132)
Pesticides	22.0	19.8	221.7-2.0	21.9	13.5	68.6-2.0	22.0	22.3	221.7-3.3	0.02 (0.983)
Energy	40.2	10.1	69.1-16.4	38.1	10.0	64.4-16.4	41.1	10.0	69.1-22.3	2.20 (0.029)
Value added (€ ha⁻¹ yr⁻¹)	299.2	73.4	545.8-95.1	316.7	77.8	545.8-120.9	290.8	69.9	457.7-95.1	–2.60 (0.010)
Environmental pressures										
Biodiversity pressure (adimensional)	0.48	0.23	1.00-0.15	0.36	0.13	0.69-0.15	0.54	0.24	1.00-0.18	6.20 (0.000)
Nitrogen balance (kg N ha⁻¹ yr⁻¹)	27.1	23.4	196.9-1.7	23.3	18.5	96.6-2.3	28.9	25.2	196.9-1.7	1.75 (0.082)
Phosphorus balance (kg P ha⁻¹ yr⁻¹)	31.1	24.5	234.0-1.5	26.6	19.5	93.6-1.5	33.3	26.3	234.0-4.9	1.99 (0.047)
Pesticide risk (g rat ha⁻¹ yr⁻¹)	771.7	748.7	7,698.3-22.6	681.2	629.4	4,763.9-31.0	815.1	797.7	7,698.3-22.6	1.30 (0.195)
Energy ratio (%)	30.8	6.0	50.0-8.7	30.1	6.0	50.0-11.8	31.1	6.0	47.6-8.7	1.27 (0.207)
Surface (ha)	123.2	94.9	750.0-0.6	168.8	72.8	398.0-40.0	101.3	96.6	750.0-0.6	–5.47 (0.000)

[a] The null hypothesis is the equality of means.

test (see the last column in Table 3), the differences between the two groups of farms are statistically significant.

In addition, the average scores recorded by the pressure-specific eco-efficiency indices for the farms participating in the F&F Scheme obtained using expression [6] are also higher for all environmental pressures under consideration, thereby demonstrating greater eco-efficiency. It is worth highlighting the favourable performance of F&F Scheme farms in relative terms in regard to the pressure on biodiversity and, albeit to a lesser extent, the pesticide risk. Meanwhile, the smallest differences are registered in relation to the energy ratio. Nevertheless, the differences between the two groups of farms are always statistically significant.

Table 2. Average crop mixes (in %)

Crop	All farms (241)	Farms included in the F&F Scheme (78)	Farms not included in the F&F Scheme (163)	t-test[a] (*p*-value)
Traditional grains	*82.6*	*72.6*	*87.4*	*7.31(0.000)*
Wheat	27.4	20.6	30.7	
Barley	50.8	47.7	52.2	
Oats	4.4	4.4	4.5	
Other crops	*17.4*	*27.4*	*12.6*	*–7.31(0.000)*
Peas	3.8	8.1	1.7	
Vetch grain	0.4	0.7	0.2	
Vetch forage	1.4	2.7	0.8	
Sunflower	3.5	4.6	3.0	
Alfalfa	2.8	3.5	2.4	
Other crops	1.9	3.2	1.3	
Fallow	3.6	4.5	3.1	
Total surface	100.0	100.0	100.0	

[a] The null hypothesis is the equality of means.

Table 3. Scores of eco-efficiency and eco-efficiency decomposition

	All farms (241)		Farms included in the F&F Scheme (78)		Farms not included in the F&F Scheme (163)		Mann-Whitney test[a] (*p*-value)
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	
Eco-efficiency							
Radial eco-efficiency	0.62	0.21	0.72	0.21	0.57	0.19	−5.01 (0.000)
Pressure-specific eco-efficiency							
Biodiversity pressure	0.56	0.24	0.71	0.22	0.49	0.21	−6.39 (0.000)
Nitrogen balance	0.46	0.27	0.59	0.30	0.40	0.23	−4.68 (0.000)
Phosphorus balance	0.51	0.26	0.62	0.28	0.46	0.24	−4.01 (0.000)
Pesticides risk	0.60	0.22	0.71	0.22	0.55	0.20	−4.91 (0.000)
Energy ratio	0.59	0.21	0.67	0.23	0.55	0.19	−3.91 (0.000)
Decomposition of radial eco-efficiency							
Managerial eco-efficiency	—	—	0.73	0.21	0.67	0.20	
Program eco-efficiency	—	—	0.99	0.02	0.85	0.09	−11.75 (0.000)

[a] The null hypothesis is that the two samples come from the same population and, therefore, have identical probability distributions.

However, the fact that F&F Scheme farms record higher eco-efficiency could simply be due to a random concentration of good managers in that group of farms rather than to more eco-efficient production technology. In order to clarify this doubt, we have performed an eco-efficiency program analysis of the farms in the sample. Specifically, we decompose eco-efficiency into the product of *managerial* or *intra-program efficiency*, obtained by comparing each farm in the sample with the best practices observed within their own group, and *program eco-efficiency*, which identifies eco-inefficiencies caused by differences in the technology between the two groups.

As regards managerial eco-efficiency, we observe that the farmers participating in the F&F Scheme could reduce their environmental pressures by 27% when compared to the best practices observed in their group, while farms not participating in that Scheme could do so by 33%. In other words, the two groups of farms registered managerial eco-efficiency scores of 0.73 and 0.67, respectively; furthermore, there are a similar number of eco-efficient farms in each program, which suggests that there is not a concentration of good managers in either of the two groups. It is nevertheless important to point out that these indicators are not directly comparable, as the eco-efficiency scores are obtained in regard to different technological frontiers.

It is a well-known fact that efficiency is always a relative concept measured in regard to a certain production technology and sample of DMUs.

Concerning program eco-efficiency, the results are as follows. Three out of every four farms included in the F&F Scheme record program eco-efficiency scores of one, indicating eco-efficient performance. The farms in this group registered an average program eco-efficiency score of 0.99 and, therefore, have the potential to reduce their environmental pressures by 1%. The farms that are not part of the F&F Scheme recorded a program eco-efficiency score of 0.85, indicating the possibility of reducing environmental pressures by 15%. In addition, only six of the 163 farms not included in the Scheme record a program eco-efficiency score of one[3]. These results suggest that the production technology used by the farms included in the F&F Scheme is more eco-efficient than that of farms not included, the differences being statistically significant at the standard confidence level according to the Mann-Whitney test.

Reduction in pressures, shadow prices and opportunity cost

The program eco-efficiency analysis performed in the previous section makes it possible to quantify the

[3] Considering all the variables in our database, we have found statistical differences between these eco-efficient farms and the remaining (eco-inefficient) 157 farms not included in the F&F Scheme only for production and related variables such as value added. As eco-efficiency is the joint result of economic and ecological performance, these six farms perform relatively well enough in economic terms to offset a not so good ecological behaviour, allowing them to shape the eco-efficient joint frontier.

potential reduction in environmental pressures that could be achieved by farms that are not included in the F&F Scheme if they decided to adopt it. These potential savings have been calculated using expression [9]; Table 4 presents the results.

If all the farms not included in the F&F Scheme decided to adopt it, they could reduce the level of excess nitrogen and phosphorous by 2.40 and 3.05 kg ha^{-1} on average, respectively. Similarly, it would be possible to reduce the biocide potential of the pesticides used by an average equivalent to 98 g of rat ha^{-1}, improve the energy ratio by reducing the contained energy in inputs by 3 kcal/100 kcal of output and, finally, reduce the average pressure on biodiversity by 4.8 percentage points.

Consequently, adopting the production technology of the F&F Scheme entails a reduction in the environmental pressures exerted per unit of value added but also a lose of value added per hectare due to having to fulfil more restrictive and environmentally friendly production requisites, which justifies compensation for adopting the F&F Scheme. Furthermore, compensation would differ from one farm to another, both due to the physical amount they should decrease each environmental pressure, and also to their shadow prices.

The shadow price of each environmental pressure has been obtained from expression [11], having previously calculated their marginal product using expression [10]. Table 4 provides some statistics for the shadow prices of the environmental pressures generated by farms not included in the F&F Scheme. As can be appreciated, and by way of example, reducing one kg of excess nitrogen would cost farms not included in the F&F Scheme an average of €2.89, while reducing one kg of phosphorous would cost €2.23 on average. Furthermore, shadow prices are strikingly varied, especially in case of the nitrogen and phosphorous balances mentioned above.

After estimating the potential reduction in environmental pressure for each farm and the corresponding shadow prices, expression [12] was used to obtain the value added lost as a result of this reduction in pressure. In other words, we have estimated the opportunity cost of the technological change that joining the F&F agri-environmental scheme would entail. Table 4 presents the results.

On average, the farms not included in the F&F Scheme should receive €54.65 ha^{-1} as compensation for the loss of value added as a result of adopting the technology of that Scheme. This figure is very similar to the baseline amount established by CAP as compen-

Table 4. Potential reduction of environmental pressures, shadow prices, and opportunity cost of reducing environmental pressures from moving to the F&F Scheme (for farms not included in the F&F Scheme)

	Mean	SD	Maximum	Number of zeros
Potential reduction of environmental pressures				
Biodiversity pressure (percentage points)	4.81	3.57	28.39	6
Nitrogen balance (kg N ha^{-1} yr^{-1})	2.40	2.19	18.15	6
Phosphorus balance (kg P ha^{-1} yr^{-1})	3.05	2.86	27.53	6
Pesticide risk (g of rat ha^{-1} yr^{-1})	98.07	141.33	1,165.32	6
Energy ratio (percentage points)	2.99	2.00	11.58	6
Shadow prices for environmental pressures[a]				
Biodiversity pressure (€ percentage point^{-1})	3.62	4.39	20.93	65
Nitrogen balance (€ kg^{-1} N yr^{-1})	2.89	14.13	145.94	108
Phosphorus balance (€ kg^{-1} P yr^{-1})	2.23	4.95	30.68	93
Pesticide risk (€ g^{-1} of rat yr^{-1})	0.30	0.30	2.32	20
Energy ratio (€ percentage point^{-1})	7.97	7.30	24.40	37
Opportunity cost of reducing environmental pressures (€ ha^{-1} yr^{-1})				
Biodiversity pressure	14.48	24.83	185.80	69
Nitrogen balance	1.69	5.27	43.67	110
Phosphorus balance	2.37	5.91	47.63	95
Pesticide risk	13.00	14.28	87.14	25
Energy ratio	23.11	28.63	155.29	39
Total opportunity cost	54.65	39.31	209.28	6

[a] Shadow prices are computed at the joint frontier.

sation for adopting the F&F Scheme (€55.89 ha⁻¹), although it is more than F&F Scheme farms have actually received on average (€36.35 ha⁻¹). It is worth to highlight here that the payment per hectare received by farms depends on both the proportion and the quantity of the surface area of farmland under the umbrella of the program. Farms only receive 100% of the baseline amount up to a maximum of 90 ha of farmland; adjusting coefficients are applied to the rest of the farmland in accordance with the minimum units of agri-environmental farmland, which define the farmland necessary for basic roles of the different crops to perform satisfactorily.

As regards the analysis by environmental pressure, it is worth highlighting the low average compensation required to reduce the pressure caused by excess nitrogen and phosphorous (€1.69 ha⁻¹ and €2.37 ha⁻¹ respectively). Furthermore, the amount of money necessary to compensate the change in production technology varies enormously from one farm to another, with a standard deviation of €39.31 ha⁻¹ and figures ranging from 0 to more than €200 ha⁻¹. Fig. 2 represents the relative frequency of compensation, revealing that the opportunity cost of adopting the F&F Scheme ranges from 0 to €25 ha⁻¹ for 25% of the farms, from €25 to €50 for 29% and from €50 to €75 for 22%, while a further 5% would require more than €125 in compensation.

Discussion

This article aims to assess the impact of the F&F Scheme on the eco-efficiency of dryland farming in the Spanish region of Castile and Leon. In order to do so, we employ DEA techniques and the program efficiency decomposition proposed by Charnes *et al.* (1981). This methodological approach makes it possible to distinguish between eco-inefficiency due to poor management on behalf of farmers and that caused by differences in production technology between the farms included in the foregoing agri-environmental scheme and those which are not.

The main results of this research are as follows. In the first place, we verify that the farms under the F&F Scheme are on average more eco-efficient than those which are not. In the second place, the production technology used by the group of farms that are part of the F&F Scheme is more eco-efficient than that used by farms that are not part of it. What is more, this
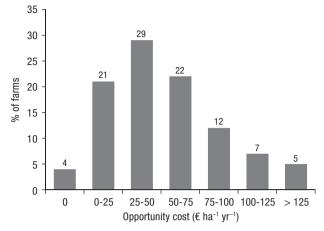

Figure 2. Opportunity cost of reducing environmental pressures for farms not included in the F&F Scheme (relative frequencies).

difference is statistically significant. In the third place, the farms not included in the F&F Scheme could substantially reduce the pressure they exert on the environment if they changed their technology by adopting the F&F Scheme. In the fourth place, the opportunity cost of adopting the F&F Scheme is, on average, similar to the payment established per hectare as compensation, but considerably higher than the average payment actually received by the farms included in the Scheme. In the fifth place, the amount of payment required to offset the decrease in value added suffered by the farms that adopt the agri-environmental scheme varies enormously.

The latter result is in line with recent research on several Spanish cereal steppes farming systems, which also conclude that the costs of implementing agri-environmental schemes might vary highly between farms (Atance & Barreiro-Hurlé, 2006; Oñate *et al.*, 2007). Furthermore, it is surprising that farms with a lower opportunity cost than the average agri-environmental payment guaranteed by CAP have not adopted the F&F Scheme. One possible reason for this could be transaction costs, which for small farms or farmers not used to such proceedings, would outweigh the difference between the payment they would receive and the opportunity cost of reducing pressure on the environment. In this case, including a fixed amount per contract could have a positive effect (Espinosa-Goded *et al.*, 2010).

As regards the agricultural policy implications stemming from our research, two recommendations can be made. In the first place, the low average cost involved in reducing nitrogen and phosphorous pressure suggests

that toughening up mandatory regulations would probably be sufficient to limit the excessive use of these fertilisers. This could be achieved by making cross-compliance stricter. In the second place, a policy based on auctions of payments per hectare would be more effective than awarding fixed amount per hectare, in view of the large differences in the compensation required by farms to join the program (Latacz-Lohmann & Van der Hamsvoort, 1997; Schilizzi & Latacz-Lohmann, 2007). This would maximize the effectiveness of this agri-environmental policy measure, either in terms of a larger number of hectares for a given amount of financial resources or lower financial costs for a given amount of farmland (Windle & Rolfe, 2008).

Finally, we must indicate that this research has been approached from a supply perspective, insofar as we only analyse the compensation needs of farms that decide to adopt an agri-environmental scheme that improves eco-efficiency. Notwithstanding, in order to justify this type of agri-environmental payments, this research should be complemented by quantifying both the ecological improvements that the agri-environmental scheme achieves and also their corresponding economic value. In this sense, this type of economic mechanisms would only be justified if they result in an improvement in social wellbeing, that is, if the valuation of environmental improvements achieved surpasses both the value added lost due to implementing them and also the payments intended to encourage such improvements (Engel *et al.*, 2008). Broadening our knowledge in this sense is undoubtedly one of the greatest challenges for future research in relation to the economic analysis of agri-environmental schemes.

Acknowledgements

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