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ARE PRODUCTION TECHNOLOGIES ASSOCIATED TO AGRI-ENVIRONMENTAL PROGRAMS MORE ECO-EFFICIENT? A CASE STUDY FOR RAIN-FED AGRICULTURE

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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. 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, employing Data Envelopment Analysis (DEA) and the program decomposition proposed by Charnes et al. (1981) to do so. 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) 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.

KEY WORDS: Data Envelopment Analysis; economic-ecological efficiency; shadow prices; agri-environmental policy.

JEL Classification: C61, D21, Q18, Q57.

1. 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), which have become the object of grow-

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ing 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 and 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. 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. 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 equivalent 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.

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.¹ The purpose of this scheme 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 programs.

The article is structured as follows. Following this introduction, Section 2 describes the methodology and Section 3 describes the sample and the variables used. Section 4 analyses the results, while Section 5 presents the conclusions and agricultural policy implications.

¹ This agri-environmental measure is part of the 2000-2006 Rural Development Program (RDP) 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).

2. Methodology

2.1. Assessing eco-efficiency with Data Envelopment Analysis

The concept of eco-efficiency, understood as the ability of production processes to create more goods and services while using fewer resources and generating less pollution, 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 $k=1, \dots, K$ farms, each of which obtains value added v_k in their production process, while at the same time generating a set of $n=1, \dots, N$ harmful environmental pressures, represented by the variables p_{nk} . Following Kuosmanen and 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:

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

After establishing the technology of reference, the eco-efficiency of a farm k^0 can be formalised as the ratio between its value added and the aggregated environmental pressure generated by its production activity:

$$\text{Eco-efficiency}_{k^0} = \frac{\text{Added value}_{k^0}}{\text{Aggregated environmental pressure}_{k^0}} = \frac{v_{k^0}}{P(p_{nk^0})} = \frac{v_{k^0}}{\sum_{n=1}^N w_{nk^0} p_{nk^0}} \quad (2)$$

where the aggregated environmental pressure is obtained as a weighted average of the individual pressures that farm k^0 exerts, w_{nk^0} being the weighting or relative importance assigned to each pressure and P an aggregation function.

Some studies weight environmental pressures on the basis of exogenous information such as expert opinions, 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^0}) that result in the best possible ranking of farm k^0 . Formally, this is written as follows (see Kuosmanen and Kortelainen, 2005):

$$\begin{aligned} &\text{Minimize } w_{nk^0} \text{ Eco-efficiency}_{k^0}^{-1} = \sum_{n=1}^N w_{nk^0} \frac{p_{nk^0}}{v_{k^0}} \\ &\text{subject to:} \\ &\quad \sum_{n=1}^N w_{nk^0} \frac{p_{nk}}{v_k} \geq 1 \quad k = 1, \dots, K \quad (i) \\ &\quad w_{nk^0} \geq 0 \quad n = 1, \dots, N \quad (ii) \end{aligned} \tag{3}$$

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

$$\begin{aligned} &\text{Minimize } \theta_{k^0, \lambda_k} \text{ Eco-efficiency}_{k^0} = \theta_{k^0} \\ &\text{subject to:} \\ &\quad v_{k^0} \leq \sum_{k=1}^K \lambda_k v_k \quad (i) \\ &\quad \theta_{k^0} p_{nk^0} \geq \sum_{k=1}^K \lambda_k p_{nk} \quad n = 1, \dots, N \quad (ii) \\ &\quad \lambda_k \geq 0 \quad k = 1, \dots, K \quad (iii) \end{aligned} \tag{4}$$

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^0 will be compared to. The solution to program (4) measures the minimum proportion of observed environmental pressures that farm k^0 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.

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:

$$\begin{aligned}
 &\text{Maximize}_{s_{k^0}^v, s_{nk^0}^v, \lambda_k} S_{k^0} = s_{k^0}^v + \sum_{n=1}^N s_{nk^0}^p \\
 &\text{subject to:} \\
 &\quad v_{k^0} + s_{k^0}^v = \sum_{k=1}^K \lambda_k v_k \quad (i) \\
 &\quad \theta_{k^0}^* p_{nk^0} - s_{nk^0}^p = \sum_{k=1}^K \lambda_k p_{nk} \quad n=1, \dots, N \quad (ii) \\
 &\quad s_{k^0}^v, s_{nk^0}^p \geq 0 \quad v=1 \text{ and } n=1, \dots, N \quad (iii) \\
 &\quad \lambda_k \geq 0 \quad k=1, \dots, K \quad (iv)
 \end{aligned} \tag{5}$$

where $\theta_{k^0}^*$ is the solution obtained from (4) for farm k^0 , $s_{k^0}^v$ the value added short-fall and $s_{nk^0}^p$ 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. Formally, these indicators would be:

$$\text{Pressure specific eco-efficiency}_{p_{nk^0}} = \theta_{k^0}^* - \frac{s_{nk^0}^p}{p_{nk^0}} \tag{6}$$

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.

2.2. 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 and Thanassoulis (2001) and O'Donnell (2008). Essentially, this approach to measuring efficiency suggests that different groups of firms 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. (2011), 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 (differences 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 y p_2 . Furthermore, there are two types of farms that carry out this type of productive activity, that is, those included in the agri-environmental flora and fauna scheme (F&F program) and those which are not (no F&F program). 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.

Figure 1 assumes we observe a set of farms participating in the agri-environmental scheme (F&F program), indicated by crosses, and another set of farms that are not part of that scheme (no F&F program) 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 observations regardless of the group they belong to, coincides with the frontier of the F&F program, as the production technology of this group is supposedly more eco-efficient.

Insert Figure 1 here

Now let us consider a farm A, which is not part of the F&F program. In the Figure we can see that, bearing in mind available production technology, 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 program 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 program F&F. 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) propose 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 program, which we assume has K_1 farms, and the no F&F program 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^0 that belongs to group K_i is a measure of its managerial or intra-program eco-efficiency, which we will refer to as $\theta_{k^0}^{* \text{ Managerial } K_i}$.

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^0 :

$$p_{nk^0}^{\text{Eco-efficient } K_i} = \theta_{k^0}^{* \text{ Managerial } K_i} \cdot p_{nk^0} \quad k^0 \in K_i \text{ and } i=1,2 \quad (8)$$

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 $\theta_{k^0}^{* \text{ Program}}$, provides an estimation of the program or inter-group eco-efficiency of farm k^0 , which is equivalent to the distance between the frontier of its own group and the joint technological frontier. If the F&F program were more eco-efficient than the no F&F program, 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 and Valdmanis, 1987; Brockett and Golany, 1996).

2.3. 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 agri-environmental scheme (no F&F program), once managerial eco-inefficiency has been cleaned up, the additional potential decrease in pressures of a farm k^0 that decided to adopt the F&F Scheme (F&F program) would be:

$$p_{nk^0}^{\text{Reduction}} = (1 - \theta_{k^0}^{* \text{ Program}}) \cdot p_{nk^0}^{\text{Eco-efficient } K_i} \quad k^0 \in K_i \text{ and } i = \text{no F\&F} \quad (9)$$

Expression (9) therefore assesses the potential reduction in each of the environmental pressures that, after adjusting to account for managerial eco-inefficiency, farm k^0 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 agri-environmental 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) (see Färe et al., 2005, 2006; Misra et al., 2007; Leleu and Briec, 2009). 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 and 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).

Finally, the opportunity cost in terms of lost value added that each farm not included in the F&F agri-environmental 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:

$$\text{Opportunity cost}_{k^0} = \sum_{n=1}^N \text{Shadow price}_{p_{nk^0}} \cdot p_{nk^0}^{\text{Reduction}} \quad k^0 \in K_i \text{ and } i = \text{no F\&F} \quad (12)$$

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 program. 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.

3. Variables and Sample

3.1. 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. Farming in this region is primarily based on extensive dryland crops, particularly cereals. For this reason the area is called the 'cereal steppes'. We chose this farming system as our case study because of its technical characteristics, because they operate in the area where the F&F Scheme has been implemented and 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., 2007a and 2007b).

The sample information on the farms analysed was obtained in the months of March and April, 2008 by quota sampling the population as a whole² 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 Common Agricultural Policy. 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. The sources of this information are detailed in the following Section.

² According to the 1999 Agricultural Census, there are a total of 7,276 farms in the area under study.

3.2. 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:

$$v_k = \frac{(\text{Sales}_k + \text{Subsidies}_k) - \text{Intermediate costs}_k}{\text{Land}_k} \quad (13)$$

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 $\text{Intermediate costs}_k$ 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:

$$\text{Biodiversity pressure}_k = p_{1k} = \frac{1}{e^{\text{SHDI}_k}} \quad (14)$$

where $\text{SHDI}_k = -\sum_{c=1}^C [s_{ck} \cdot \ln(s_{ck})]$, and $s_{ck} = \frac{\text{Land}_{ck}}{\text{Land}_k}$

In addition, Land_{ck} represents the number of hectares that farm k devotes to crop c ($c=1, \dots, C$), 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.³ 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:

$$\text{Nitrogen balance}_k = p_{2k} = \sum_{c=1}^C (\text{Nitrogen input}_{ck} - \text{Nitrogen output}_{ck}) \cdot s_{ck} \quad (15)$$

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.

³ By way of example, if the variable *Biodiversity pressure* takes a value of 0.10, the pressure exerted on biodiversity would be equivalent to that exerted by a farm which devotes 10% of its farmland to each crop. This indicator considers obtaining two types of crops devoting 50% of farmland to each (indicator score of 0.5) is equivalent in terms of biodiversity to a farm obtaining four types of crops and devoting entirely unequal percentages of farmland to each (a score of 0.502 would represent a farm that cultivates four products, devoting 80%, 10%, 8% and 2% of total farmland respectively).

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:

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

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 exerts on the environment. This indicator has been estimated by adding the potential lethality of all phytosanitary products used for agricultural production in regard to live organisms, measured in kg of rat per hectare. The specific formula used to obtain this pressure from farm k is:

$$\text{Pesticide risk}_k = p_{4k} = 1000 \cdot \sum_{c=1}^C \left(\sum_{m=1}^M \frac{1000 \cdot \text{Commercial product}_{mck} \cdot \text{Active principle concentration}_m}{\text{Lethal dose } 50_m} \right) \cdot s_{ck} \quad (17)$$

where *Commercial product_{mck}* is the quantity of commercial product m applied per hectare and year to grow crop c in kilograms per hectare, *Active principle concentration_m* is the concentration of active principles in product m in percentage and *Lethal dose 50_m* is the total lethal dose 50%⁴ expressed in milligrams of product m per kilogram of rat.

The pesticide risk accounts for the biocide potential of the pesticides used by farm k (in grams of rat per hectare and per year). The higher the value of this indicator, the more pressure the farm exerts on the environment.

⁴ The lethal dose of 50% indicates the amount of the active substance that would kill half the animals in a laboratory experiment, expressed in milligrams of substance per kilo of animal. Rats are usually used to conduct these experiments, which is why the variable is expressed in milligrams of substance per kilogram of rat.

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 described in the paragraphs above for the sample of farms and for each of the groups considered, namely farms participating in the F&F Scheme and those which are not. The 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.

Insert Table 1 here

4. Results

4.1. Eco-efficiency assessment (joint frontier)

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 2.

Insert Table 2 here

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 envi-

ronment 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 test (see the last column in Table 2), 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 running program (5) 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.

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.

4.2. Managerial eco-efficiency and program eco-efficiency

This Section presents the results of applying the program efficiency approach described in Section II.2 to our two groups or programs of farms, namely those included in the F&F Scheme (F&F program) and those that are not (no F&F program). The results are displayed in Table 3 and include various descriptive statistics for the indices of *managerial* or *intra-program efficiency*, obtained by com-

paring each farm in the sample with the best practices observed within their own group, and for *program eco-efficiency*, which identifies eco-inefficiencies caused by differences in the technology between the two groups.

Insert Table 3 here

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.⁵ 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 decision making units.

As regards 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. These results suggest that the production technology used by the farms included in the F&F Scheme is evidently more eco-efficient. This result is confirmed by the t-test comparing averages and the Mann-Whitney rank test (see Table 3), which clearly reveals statistically significant differences between the eco-efficient frontiers of the farms included in the F&F Scheme and those which are not.

⁵ 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.

4.3. Reduction in pressures, shadow prices and opportunity cost

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

Insert Table 4 here

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 per hectare on average, respectively. Similarly, it would be possible to reduce the biocide potential of the pesticides used by an average equivalent to 98 grams of rat per hectare, improve the energy ratio by reducing the contained energy in inputs by 3 kilocalories per 100 kilocalories 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 the shadow price.

The shadow price of each environmental pressure has been obtained from expression (11), having previously calculated their marginal product using expression (10). Table 5 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. Similarly, shadow prices are strikingly varied, especially in case of the nitrogen and phosphorous balances

mentioned above. Shadow prices also vary a great deal for the rest of pressures, albeit to a slightly lesser extent.

Insert Table 5 here

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 6 below presents the results.

Insert Table 6 here

On average, the farms not included in the F&F Scheme should receive €54.65 per hectare 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 compensation for adopting the Agri-environmental Extensification Scheme for the Protection of Flora and Fauna (€55.89/ha), although it is more than F&F Scheme farms have actually received on average (€36.35/ha).⁶ 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 and €2.37/ha 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 and figures ranging from 0 to more than €200/ha. Figure 2 represents the relative frequency of compensation, revealing that the opportunity cost of adopting the F&F Scheme ranges from 0 to €25 per hectare for 25% of the farms, from €25 to €50 for 29% and from €50 to €75 for 22%, while a further 6% would require more than €125 in compensation.

⁶ The payment per hectare received by farms depends on 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 hectares of farmland; adjusting coefficients are applied to the rest of the farmland in accordance with the minimum units of agri-environmental farmland (MUAUF). The MUAUF define the farmland necessary for basic roles of the different crops to perform satisfactorily, bearing in mind the socioeconomic characteristics of agriculture in the area.

Insert Figure 2 here

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).

5. Conclusions and agricultural policy implications

This article aims to assess the impact of the Agri-environmental Extensification Scheme for the Protection of Flora and Fauna on the eco-efficiency of dryland farming in the Spanish region of Castile and Leon. In order to do so, we employ Data Envelopment Analysis (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 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 Scheme. In the fourth place, the opportunity cost of adopting the 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 F&F 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.

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 and Van der Hamsvoort, 1997; Schilizzi and 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.

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.

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Figure 1. Managerial and program eco-efficiency

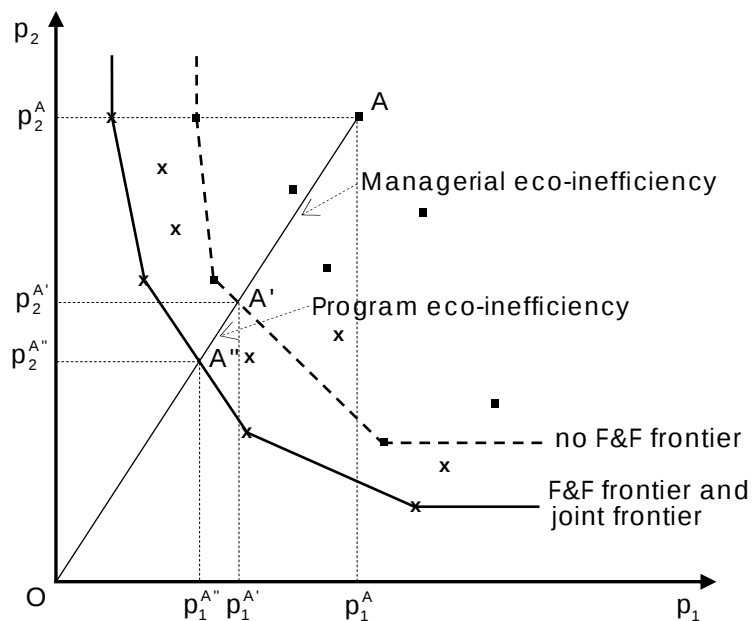


Figure 2. Opportunity cost of reducing environmental pressures for farms not included in the F&F Scheme (relative frequencies)

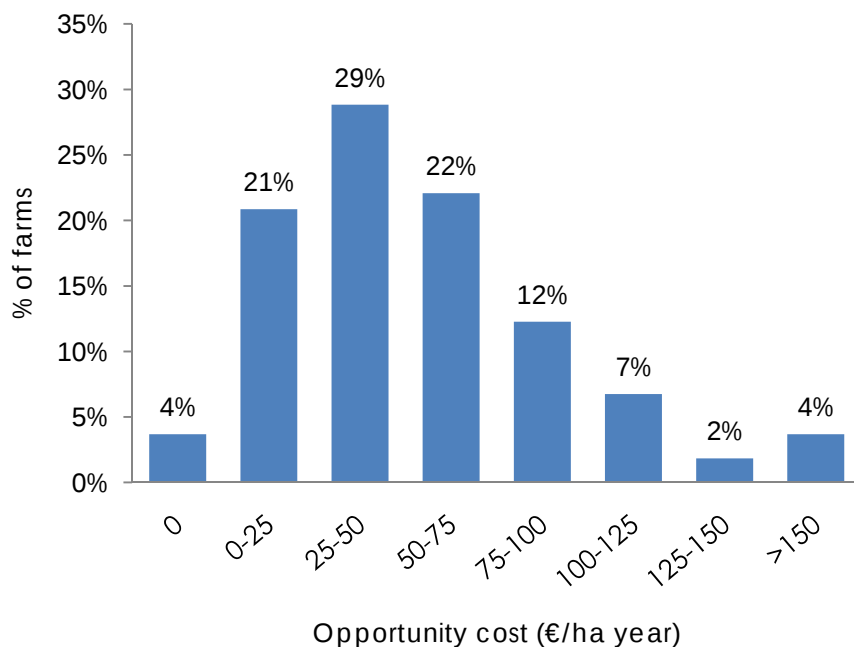


Table 1. Sample description

	All farms (241)		Farms included in the F&F Scheme (78)		Farms not included in the F&F Scheme (163)		t-student (p-value)
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	
<i>Output</i>	508.39	68.39	515.72	72.47	504.90	66.30	-1.16 (0.247)
Sales (€/ha·year)	461.56	66.33	446.09	69.22	468.97	63.80	2.53 (0.012)
Coupled subsidies (€/ha·year)	35.06	5.71	33.28	6.10	35.91	5.33	3.42 (0.001)
F&F Scheme subsidies (€/ha·year)	11.77	18.10	36.35	10.77	0.00	0.00	-43.2 (0.000)
<i>Inputs</i>	209.21	46.25	198.92	43.90	214.12	46.67	2.41 (0.017)
Seeds (€/ha·year)	54.18	12.73	52.27	10.84	55.09	13.48	1.61 (0.109)
Nitrogen (€/ha·year)	67.13	43.07	62.32	39.20	69.44	44.73	1.20 (0.231)
Phosphorus (€/ha·year)	25.77	10.10	24.35	9.33	26.45	10.41	1.51 (0.132)
Pesticides (€/ha·year)	21.96	19.81	21.92	13.48	21.98	22.26	0.02 (0.983)
Energy (€/ha·year)	40.16	10.09	38.12	10.02	41.14	10.00	2.20 (0.029)
Value added (€/ha·year)	299.18	73.43	316.73	77.79	290.78	69.94	-2.60 (0.010)
<i>Environmental pressures</i>							
Biodiversity pressure (%)	47.88	22.55	35.82	12.58	53.65	23.97	6.20 (0.000)
Nitrogen balance (kg N/ha·year)	27.05	23.35	23.27	18.53	28.86	25.19	1.75 (0.082)
Phosphorus balance (kg P/ha·year)	31.13	24.46	26.61	19.45	33.29	26.31	1.99 (0.047)
Pesticide risk (g rat/ha·year)	771.73	748.71	681.19	629.42	815.05	797.70	1.30 (0.195)
Energy ratio (%)	30.80	6.04	30.09	6.04	31.14	6.03	1.27 (0.207)

Table 2. Scores of eco-efficiency (joint frontier)

	All farms (241)		Farms included in the F&F Scheme (78)		Farms not included in the F&F Scheme (163)		Mann-Whitney test ⁽¹⁾ (p-value)
	<i>Mean</i>	<i>Standard deviation</i>	<i>Mean</i>	<i>Standard deviation</i>	<i>Mean</i>	<i>Standard deviation</i>	
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)

⁽¹⁾ The null hypothesis is that the two samples come from the same population and, therefore, have identical probability distributions.

Table 3. Eco-efficiency decomposition: managerial eco-efficiency and program eco-efficiency (group frontiers)

	<i>Mean</i>	<i>Standard deviation</i>	<i>Maximum</i>	<i>Minimum</i>
<i>Managerial eco-efficiency</i>				
Farms included in the F&F Scheme	0.73	0.21	1	0.31
Farms not included in the F&F Scheme	0.67	0.20	1	0.17
<i>Program eco-efficiency</i>				
Farms included in the F&F Scheme	0.99	0.02	1	0.84
Farms not included in the F&F Scheme	0.85	0.09	1	0.59
<i>Comparisons of program eco-efficiency between farms included and not included in the F&F Scheme</i>				
<i>t-test</i>				
Difference of means	-0.14			
t-statistic (p-value)	-13.57 (0.000)			
<i>Mann-Whitney test</i>				
Z-statistic (p-value)	-11.75 (0.000)			

Table 4 Potential reduction of environmental pressures from moving to the F&F Scheme (for farms not included in the F&F Scheme)

	<i>Mean</i>	<i>Standard deviation</i>	<i>Maximum</i>	<i>Number of zeros</i>
Biodiversity pressure (percentage points)	4.81	3.57	28.39	6
Nitrogen balance (kg N/ha·year)	2.40	2.19	18.15	6
Phosphorus balance (kg P/ha·year)	3.05	2.86	27.53	6
Pesticide risk (g of rat/ha·year)	98.07	141.33	1165.32	6
Energy ratio (percentage points)	2.99	2.00	11.58	6

Table 5. Shadow prices for environmental pressures computed at the joint frontier
(for farms not included in the F&F Scheme)

	<i>Mean</i>	<i>Standard deviation</i>	<i>Maximum</i>	<i>Number of zeros</i>
Biodiversity pressure (€/percentage point)	3.62	4.39	20.93	65
Nitrogen balance (€/kg N·year)	2.89	14.13	145.94	108
Phosphorus balance (€/kg P·year)	2.23	4.95	30.68	93
Pesticide risk (€/g of rat·year)	0.30	0.30	2.32	20
Energy ratio (€/percentage point)	7.97	7.30	24.40	37

Table 6. Opportunity cost of reducing environmental pressures from moving to
the F&F Scheme (for farms not included in the F&F Scheme)

	<i>Mean</i>	<i>Standard deviation</i>	<i>Maximum</i>	<i>Number of zeros</i>
Biodiversity pressure (€/ha·year)	14.48	24.83	185.80	69
Nitrogen balance (€/ha·year)	1.69	5.27	43.67	110
Phosphorus balance (€/ha·year)	2.37	5.91	47.63	95
Pesticides risk (€/ha·year)	13.00	14.28	87.14	25
Energy ratio (€/ha·year)	23.11	28.63	155.29	39
Total opportunity cost (€/ha·year)	54.65	39.31	209.28	6