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ANALYSIS

Environmental spillover effects on firm productivity and efficiency: An analysis of agri-food business in Southeast Spain

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ABSTRACT

Spillover effects are treated as the influence of knowledge and innovation diffusion on an economic activity, but their analysis related to environmental practices within firms is still quite scarce. This study investigates the effect of environmental practices and related spillovers on productivity and efficiency in agri-food firms located in Southeast Spain. The low investment in research and development actions in comparison with the industrial sector, together with the relatively recent application of environmental requirements and the heterogeneity of environmental controls within firms have led to important changes in the organisation and management of their productive activity. These features are especially related to the implications that location and clustering factors have on environmental knowledge and innovation diffusion. Taking environmental management practices as knowledge of capital, we propose a specific analysis that evaluates the impacts of both environmental investment and spillover on the production function. The results indicate the relationship between productivity improvement and environmental practices, also showing the presence of positive spillovers. In a second-stage analysis, the incidence of environmental variables on the individual technical efficiency of firms is also determined. On the whole, the empirical analysis provides evidence of the links between environmental practices spillovers and economic performance.

1. Introduction

The analysis of environmental knowledge and innovation has received increasing attention in recent years (Mazzanti and Zoboli, 2006). Empirical evidence has shown the complementarity between environmental management and innovation (e.g. Frondel et al., 2005; Rennings et al., 2006) and its inter-firm diffusion (e.g. Snyder et al., 2003).

However, the joint analysis of environmental knowledge diffusion effects and their incidence on firm productivity and efficiency has received less attention. This analysis is particularly relevant, since eco-innovation and eco-efficiency constitute key issues to achieve equilibrium between ecological problems and economic activity (Anton et al., 2004; Beise and Rennings, 2005).

Several studies have related the firm's investment in environmental practices to competitiveness and financial performance (e.g. Russo and Fouts, 1997; Sharma and Vredenburg, 1998). Nevertheless, they do not analyse the moderating role of the characteristics of the companies' environment (e.g.

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the existence of networks of companies located nearby) to explain the relationship between environmental investment and financial performance (Mazzanti and Zoboli, 2006). One external factor that moderates the relationship between environmental investment and firm performance may be the spillover effects related to networks and industrial agglomeration (Galdeano-Gómez et al., in press). As noted by Beise and Rennings (2005), environmental innovations are particularly important in local industrial frameworks since they may give rise to a “double externality”: (1) the reduction of environmental externalities, and; (2) the typical R&D spillover effect (Jaffe et al., 2005). On one hand, environmental innovations can improve the competitiveness of firms located in a given region, and on the other hand, they can contribute to reducing the negative impact on their natural environment.

Most studies connect spillovers with R&D stock as main knowledge capital. In the framework of productivity analysis, spillovers may be considered as another input of the knowledge production process of a firm, industry or country (e.g. Griliches, 1992; Mairesse and Mohnen, 2002). Likewise, spillover effects are linked to the transfer of environmental knowledge, which is facilitated by the proximity of firms operating in the same geographical region, and may be considered as an input of firm’s production function.

The present work aims to study environmental management practices spillovers and their impact on corporate productivity and efficiency, taking as reference the agri-food firms located in the Southeast Spain, which fulfil certain clustering characteristics (Pallarés-Barberá, 2002). Unlike other works focussing on management, e.g. resource-based view (see Galdeano-Gómez et al., in press), we develop a framework for environmental spillovers following several approaches of knowledge spillovers analysis (Bassant and Fikkert, 1996; Adams, 2006) and use insights into the interaction between companies located in the same geographical area (i.e. geographical clusters) as a driving factor for the development of knowledge (Tallman et al., 2004).

The structure of this work is as follows: Section 2 reviews the literature on environmental management practices and spillovers. Section 3 specifies the methods and variables. Section 4 shows the results of the estimations, and Section 5 presents the discussion and conclusions.

2. Environmental practices and spillovers

The literature includes many research works addressing the relationship between environmental practices or capabilities and firms’ performance in different industries (e.g. Klassen and Whybark, 1999; Russo and Fouts, 1997). The capabilities associated with the environmental innovations and knowledge can contribute to firm productivity by both cost reduction and product differentiation (Shrivastava, 1995).

The innovation[1] can lead to waste reductions and/or greater efficiency in production processes. In food production typical examples of cost advantages from environmental practices are: selling to recycling plants the plastic greenhouses are made of, the use of smaller amounts of more accurate fertilisers and pesticides, improvements in the irrigation system in order to save water, and avoiding product take-back costs derived from not fulfilling environmental standards (Chambers and Eisgruber, 1998; Ecker and Coote, 2005). Although one of the main motivations the firm to introduce new or modified processes and practices may be cost reduction, these innovations may also contribute to reducing environmental damage.[2] For instance, biological food creates benefits for both the firm (e.g. saving natural inputs) and the environment (e.g. less pesticide pollution) (Beise and Rennings, 2005).

Product differentiation typically arises from the customers’ perception that the product is more valuable. Organic products are a typical example of value added by environmental practices. Environmentally sound agricultural products have better market access and customers perceive those products as healthier and fulfilling higher quality standards (Walley et al., 2000).

In addition to these business motivations, the diffusion effect plays an important role in the application of new practices and techniques, especially by exploiting networking relationships and knowledge spillovers due to proximity and internal resources, firms may increase the environmental performance of the productive area (Mazzanti and Zoboli, 2006). It has been suggested that geographical proximity increases the probability of knowledge transmission between organisations (Maskell and Malmberg, 1999; Tallman et al., 2004). Similar concepts have been proposed by researchers to describe the development of specific knowledge in geographical clusters. For instance, Malmberg and Maskell (2002) refer to learning networks to explain the competitive advantages of industrial districts.

Spillover effects are defined as the interdependence between one type of knowledge and another, whose frontiers change, requiring interpretation and communication (Storper, 1997). Spillovers are dynamic processes of knowledge diffusion between different organisations. Interactive feed-back between actors plays an important role in those processes, making this knowledge evolve and improve through interactions over time.

Both tacit and explicit information can be gathered by firms through formal and informal interactions with other organisations in the area – and the people working in them – about issues such as technological paths followed by competitors or the success or failure of tactical and strategic decisions of competitors. Those interactions between managers and

[1] According to the definition made by Rennings (2000), we consider that environmental innovations consist of new or modified processes, techniques, practices, systems and products to avoid or reduce environmental harms.

[2] Although cost reducing innovations may result in increased pollution due to greater production, the likelihood of this happening is less if we take into account two factors. On the one hand cost reductions do not necessarily lead to lower prices (in fact, in the case environmental investment, the advantages in costs and product differentiation tend to appear simultaneously — Shrivastava, 1994). On the other hand, an increase in production of eco-efficient companies may more than compensate, in terms of the pollution generated, for the lower production of companies with higher costs, i.e. more eco-inefficient firms (e.g. Russo and Fouts, 1997).

specialised workers of different organisations may be due to idiosyncratic circumstances derived from sharing geographical location (Malmberg and Maskell, 2002), e.g. casual personal relations, accidental personnel exchange, providing to the same customers and having the same providers, contacts with the same local institutions – universities, regional associations, public administrations, etc. – or attending industry meetings and fairs.

In this way, the tacit knowledge used in the decision process is shared by firms (Powell et al., 1996). For example, if a company chooses a technological option for an environmental problem which turns out to be a failure, its competitors will probably prefer another option, whose success or failure will also be known by its rivals and providers in the same geographical area. Therefore, repeated interactions between all the companies in the industry, and the resulting spillover effects, generate a collective knowledge transfer that is widespread for the companies in the area, but is very difficult to observe for firms located anywhere else (Tallman et al., 2004). This "social capital" is dynamic and evolves through spillover processes.

Production concentrated in a given geographical area implies a bigger market for providers of technical solutions for environmental problems. Maier and Finger (2001) suggest that organic agricultural foods also tend to be challenged by marketing problems such as supply regularity and product labelling and identifying. These problems can be better faced by a company if it is surrounded by many others in the same geographical area producing the same products. Spillovers also reduce uncertainty about the implementation of environmental practices. The risk perception of the firm can be lessened as a consequence of the absorption of the new knowledge of technologies and its incidence on both environmental and economic performance (Snyder et al., 2003).

Transmission of environmental knowledge on tools and specific practices within the network of companies facilitates the development of "green competencies" at this collective level. Nevertheless, each company will integrate this general knowledge with more or less efficiency, in such a way that green competencies at firm level can evolve with varying degrees of intensity (Tallman et al., 2004). Thus, it is to be expected that companies which already posses extensively developed environmental practices can obtain greater efficiency gains from the spread of specific environmental knowledge within the network.

3. Methods

3.1. Sample features

The empirical analysis has been based on balanced panel data using the annual financial reports of 62 farming–marketing firms located in Southeast Spain, over the period 1995–2003.[3] In terms of output, our sample accounts for 84% of the regional production, which is representative of Spanish agri-food produce (particularly for vegetables), accounting for 34% of the total national volume.

This agri-food system, based on greenhouses, has implied intensive use of soil, water, fertilisers, insecticides, and raw materials (plastics, packaging, etc.) generating high levels of waste (Downward and Taylor, 2007). Environmental management control in these firms was intensified during the 90's, when different European Common Agricultural Policy programmes were applied to environmental management. Representative firms in our empirical setting have a cooperative or associative nature, and according to Community Regulation, they are classified as Organisations of Producers (OP). The main objective of these firms is to manipulate and commercialise their associates' (farmers) products in their warehouses and installations linking the farming and marketing activities. They are proving to be key elements in the development of environment-friendly practices due to their direct contact with farmer members, which makes it easier to explain environmental regulation and to apply controls and audits. These entities can develop environmental investment practices, which result in increases in productivity, but which the growers as individuals would be unable to make due to the small scale of their firms.

Moreover, the vast majority of OPs are members of local associations. These and other organisations within the agri-food system play different representation roles of the collective (for instance, negotiating with public administrations the elaboration of incentive policies for the adoption of environmental practices), research centres, exports promotion, etc. (Pallarés-Barberá, 2002). These entities act as the central organisation of a geographical cluster (Malmberg and Maskell, 2002) and take on the tasks of training and the transfer of information on "best practices" (e.g. of environmental and food quality).

Many of these firms are increasing their investments in the implementation of environmental management practices, including activities aiming to prevent environmental impacts through recycling waste, reducing the use of fertilisers, monitoring pesticides concentration throughout the production process, diminishing soil pollution and water consumption, etc. (Downward and Taylor, 2007). Another set of practices aims to instil ecological principles in production through the implementation of integrated pest management, the renewal of irrigation systems and the implementation of technologies that prevent soil pollution (Céspedes-Lorente and Galdeano-Gómez, 2004). These environmental practices have been applied with a certain degree of heterogeneity and at times they have been related to the main process of innovation and managerial change in the sector.

3.2. Empirical model

In the present study, the corporate production function includes environmental practices and the related spillovers as the main components in the development of new technologies and management methods (knowledge). Thus, the expanded production function with a measure of knowledge capital (see, for instance, Griliches and Mairesse, 1984) is as follows:

$$Y_{it} = F(C_{it}, L_{it}, K_{it}) \tag{1}$$

[3] This agri-food industry in Southeast Spain has developed over the last three decades and since the 1990's it has been relatively stable. In the period under study only two firms entered and one exited the sector, and the effect of sample attrition is of little significance. Consequently, a balanced panel is considered suitable for the proposed analysis.

where Y is a measure of output, C is the physical capital, L is a measure of labour and K is the knowledge capital (which can include the correspondent of the firm and spillovers); the subscripts refer to the firm i and the current year t.

Considering that a firm's environmental performance is influenced by its neighbours' environmental practices and their management leads us to adjust the production relationship. In other words, the exogenous variations of environmental spillover can influence the environmental investment decision of a firm and then have an impact on productivity. When the effect of knowledge spillover to firm i from an external source is taken into account, it is partly determined by firms and serves as an endogenous variable (Jaffe et al., 1995; Chen and Yang, 2005; Adams, 2006). Thus, the expression for knowledge K_{it} (now KE $_{it}$) should be a function including environmental management practices and environmental spillover shown as follows:

$$KE_{it} = f(EP_{it}, ES_{it}) \tag{2}$$

where EP_{it} is the stock of knowledge capital generated by firm i indexed by environmental practices, and ES_{it} is the environmental practices spillover from other firms in the same industry.

The production function $F(\cdot)$ has been usually modelled as Cobb–Douglas in spillovers studies. This option is preferable to using a generalised functional form, as these imply strong assumptions about the spillover effects, the appearance of multicollinearity problems and the difficulty of interpretation of estimated parameters (Griliches and Mairesse, 1998).[4] Thus, assuming a Cobb–Douglas production function, Eq. (1) can be approximated as follows (Bassant and Fikkert, 1996):

$$Y_{it} = Ae^{\lambda t}C_{it}^{\alpha}L_{it}^{\beta}e^{KEit}e^{\varepsilon it} \tag{3}$$

where A is a constant term, λ is the rate of disembodied exogenous technical change (the time trend λt is usually replaced by time dummies in the estimation); α, β, the corresponding elasticities, and ε is the random error term for the equation, reflecting the effect of unknown factors, differences in technologies across firms and other disturbances. The stock of environmental knowledge, KE_{it}, takes the linear functional form as follows (Fuss et al., 1978; Chen and Yang, 2005):

$$KE_{it} = \gamma_{ep}(EP_{it})^{1/2} + \gamma_{es}(ES_{it})^{1/2} + \gamma_{eps}(EP_{it})^{1/2}(ES_{it})^{1/2} \tag{4}$$

here we have three parameters, γ_{ep}, γ_{es} and γ_{eps}, related to environmental factors. As regards environmental spillovers, we can consider γ_{es} as "direct effect" while γ_{eps} reflects an "indirect effect" on productivity.

To implement the estimation, taking logs of Eq. (3) and substituting for KE $_{it}$ from Eq. (4) we obtain the following form[5]:

$$\begin{aligned} y_{it} = a + \lambda t + \alpha c_{it} + \beta l_{it} + \gamma_{ep}(EP_{it})^{1/2} + \gamma_{es}(ES_{it})^{1/2} \\ + \gamma_{eps}(EP_{it})^{1/2}(ES_{it})^{1/2} + \varepsilon_{it} \end{aligned} \tag{5}$$

here c_{it} and l_{it} represent the natural logarithms of C_{it} and L_{it} respectively. The Ramsey reset test was conducted for functional form misspecification using square, and both square and cubic fitted values of the output.[6] Results (considering the two unrestricted models) show small F-values and their corresponding p-values of 0.42 and 0.27 respectively, are well above the conventional significance level of 0.05.

On exploring the relationship between environmental knowledge and productivity growth, we allow for the existence of individual effects, which are potentially correlated with the right hand side regressors. The error term may be decomposed as

$$\varepsilon_{it} = \mu_i + \xi_{it} \tag{6}$$

where μ_i stands for the firm (time-invariant) specific effect that accounts for the possible heterogeneity across firms (for example, in their technological efficiency), whereas ξ_{it} is a white noise error term and reflects temporary effects with finite moments.[7]

In this way, the possibility of existing individual effects (μ_i), whether fixed or random, can be considered in the econometric analysis of panel data. The suitability of dealing with these effects as fixed or as random depends on whether or not correlated with the explanatory variables. If μ_i presents the above-mentioned correlation, the OLS (Ordinary Least Squares) estimator is inconsistent and the WG (Within Group) estimator should be considered; in such a case, the μ_i constitutes a set of additional coefficients (within group) in the model. If the μ_i represents a random variable (independent of explanatory variables) the OLS estimator would be consistent but inefficient because the error term is not white noise, and the GLS (Generalised Least Squares) estimator would be suitable.

Another important issue is that the estimations of production function are often affected by biases due both to simultaneity and to measurement errors in the inputs. In order to get the robust estimation of standard errors we can use the 'long-difference' approach developed by Griliches and Hausman (1986).[8] This consists of regressing the log difference of firm's output between the starting and ending period of the 'long' log difference in levels of capital input, labour input and environmental knowledge variables. This will be applied in each estimation method.

In a second stage, it is worth here estimating the individual fixed effect to determine the incidence on the efficiency of each firm (especially the impact of environmental variables). To this end, we can consider a lineal estimation method of μ_i (Novales, 1996):

$$\hat{\mu}_i = \left[\sigma_\mu^2 / \left(T\sigma_\mu^2 + \sigma_\varepsilon^2\right)\right] \cdot 1_T' \left(y_i - X_i\hat{\beta}\right) \tag{7}$$

where T is the sample period number (t=1, ..., T), $1_T'$ is a column vector (inverse) constituted by T ones, X_i is the

[4] The Appendix includes some considerations about alternative functional forms.

[5] Nevertheless, the variables of environmental knowledge are not taken in logarithms and this specification does not lend itself to the constraint of constant returns to scale (Chen and Yang, 2005).

[6] This test is also used for all equations in Tables 3 and 4.

[7] In particular: $E(\xi_{it})=E(\xi_{it}\xi_{js})=0$ for $t \neq s$ and $i \neq j$.

[8] Another approach widely used is the Generalized Method of Moments. Nevertheless, for the sake of simplicity in estimations we consider that 'long-difference' may be a feasible remedial method.

explanatory variable vector and $\hat{\beta}$ represents the parameter vector estimated. This estimation can be interpreted as a residual proportion of GLS assigned to μ_i and determined by the relative variances σ_μ^2 and σ_ε^2 (whose values are given through GLS and WG estimations).

When the μ_i estimations are obtained, they may be used as technical efficiency measures (TE) making the following normalisation in which TE of firm i is bounded in the [0,1] interval:

$$\mathrm{TE}_i = \exp\left(\hat{\mu}_i - \max\hat{\mu}_j\right) \tag{8}$$

where max $\hat{\mu}_j$ is the maximum sample of the estimated fixed effects, and $\hat{\mu}_i$ is the estimated fixed effect of firm i. In order to detect any systematic variation in efficiency across firms, particularly due to the spillover (direct and indirect) effects, we suggest a linear model as follows (Söderbom and Teal, 2004):

$$\mathrm{TE}_i = \theta_0 + X_i\theta + Z_i\rho + v_i \tag{9}$$

where X_i is the vector of inputs and Z_i represents the vector of firm's characteristics and market structure.[9] These variables are measured as the firm means (i=1,…,62) in the analysed period.

3.3. *Variables specification*

The dependent variable, *y*, in Eq. (5) denotes a value added (VA) as firm's output.[10] This has been corrected for inflation using the output deflator constructed from the sector data contained in the National Accounts of Spain (base year 1995).

The capital stock, C, is a constructed estimate of equipment and plant, also adjusted for inflation. The labour input, *L*, is calculated from the total hours worked in each year. In this case we have considered the existence of workers specialised in environmental management (technicians, engineers, etc.) of the firms analysed. In order to avoid an excess environmental performance elasticity (as pointed out by Mairesse and Hall, 1996, regarding R&D elasticity) we have corrected the labour measure.

In order to construct the EP variable, we can consider the accumulative effect on the value added, as is usual for R&D expenditures. Following this methodology, the EP as stock for period t, is obtained from the annual expenditure on environmental practices in period *t* plus the accumulative investment up to period *t*−1, applying a deflator (η): $\mathrm{EP}_{it} = Aep_{it} + (1-\eta)\,\mathrm{EP}_{i(t-1)}$.

This can be developed as follows (Hall and Mairesse, 1995):

$$\begin{aligned}\mathrm{EP}_{i1} &= Aep_{i0} + (1-\eta)Aep_{i(-1)} + (1-\eta)^2 Aep_{i(-2)} + \ldots \\ &= Aep_{i1}/(g_i + \eta)\end{aligned} \tag{10}$$

Variables	Mean	Standard deviation	Minimum	Maximum
ln VA	2.94	3.15	0.89	5.07
ln C	6.03	7.98	2.41	10.76
ln *L*	7.10	4.83	3.25	9.06
$(\mathrm{EP})^{1/2}$	24.87	39.58	11.16	62.38
$(\mathrm{ES})^{1/2}$	174.66	88.93	109.23	210.03
$(\mathrm{EP})^{1/2}(\mathrm{ES})^{1/2}$	4621.43	1578.17	2792.26	5408.70
Age	12.32	7.29	8.00	17.00
Size	9315.18	4207.31	3189.42	14 508.94
Competition index	0.07	0.01	0.06	0.09

Table 1 – Descriptive statistics of variables (average of the period 1995–2003)

Number of observations = 558. The variables in levels are measured in thousands of euros.

where *g* represents the growth rate of environmental expenditure. As regards the deflator, η, assuming that the depreciation may be different in comparison with traditional R&D capital, we opt to follow recent works on environmental input in Spanish firms (Garcés and Galve, 2001; Céspedes-Lorente and Galdeano-Gómez, 2004) that apply a deflator of 10%, considering two lagged years.

In constructing the environmental spillover, ES, we adopt a similar method to EP, measuring the environmental practices by firms in the same region other than firm i in this sector, as follows: $\mathrm{ES}_{it} = \sum_{j=1}^{J} \mathrm{EP}_{jt} \ \ \forall j \neq i$.

Regarding the firm's individual fixed effects, we consider the firm's age and size (measured as total sales), and an indicator of competitive interactions (by using the Hirschman–Herfindahl index, HH).[11] The descriptive statistics are shown in Table 1.

4. Estimation and results

In order to select the most suitable estimation, the OLS, WG and GLS regressions have been previously carried out. Table 2 shows the R^2 (adjusted) results and the statistics used to select the estimators. To perform WG estimation, a model with six groups (based on *F* and likelihood ratio tests) which show a more homogeneous behaviour in the sample of firms is selected. The results obtained show that WG performs the estimation better than OLS and GLS estimations.[12] Taking as reference the Breusch–Pagan test we have to assume the existence of firm's individual effects, and considering the value of Lagrange multiplier ratio these can represent a relevant differentiation across the sample. Following the Haussman test, we reject the hypothesis that these effects are random variables and, for this reason, we have to accept that there are firm's fixed effects. We therefore focus on the results of WG estimators using fixed effects panel method.

[9] In this case we consider the size, age and a measure of the degree of competition in the sector, which can influence the technical efficiency across firms in presence of spillover effects. An appropriate extension related to TE would be to consider other exogenous variables that determine the (in)efficiency of the firm, in either a first-stage approach or a second-stage approach (e.g. Sickles, 2005).

[10] We use the value added as dependant variable, as a better indicator of the environmental quality incorporated to the final product, following analyses such as those by Seddon et al. (1993), and Tyteca et al. (2002).

[11] In order to obtain an average ratio in the analysed period for each firm *i*, this ratio is calculated by summing the squares of the individual market shares of all the other firms in the sample. This measure is usually used as competition or rivalry index for each firm (e.g. Cool and Dierckx, 1993; McGill, 2007).

[12] These results are available upon request.

Table 2 – Tests of estimations of Eq. (5)

Estimation method	OLS	WG	GLS
R^2 (adjusted)	0.708	0.846	0.659
Breusch–Pagan test: individual effects model vs. within individual effects model			
Statistic	Value	*df*	*p*-value
Lagrange multiplier	119.14	1	0.0000
Hausman test: fixed effects model vs. random effects model			
Statistic	Value	*df*	*p*-value
Chi-square	17.98	5	0.0026

Table 3 shows WG estimations considering three models. Model I, excludes the spillover variables. Model II excludes the interaction term (spillover indirect effect), and model III includes all regressors.

It can be seen that physical capital (C) has a positive impact on the value added, although the result (0.236) is rather low compared to other analyses in the Spanish or international context.[13] This coefficient is certainly higher for the OLS and GLS estimations, so it indicates that part of the capital variable impact may be reflected in the firm's individual effects, μ_i, in the WG estimation.

Although the labour coefficient is positive and significant, the parameters (in the three estimations) also reflect less impact than the referenced studies. This is probably due to the adjustment made to avoid simultaneity (in hours worked) with the environmental variable.

The relationship between value added and the firm's environmental investment is both significant ($p<0.01$) and positive. Unlike other analyses on the industrial sector (e.g. Shrivastava, 1995; Garcés and Galve, 2001), which obtain a low or negative impact of environmental variables, our results may be indicative of the greater relevance of environmental factors on food products. The environmental spillover direct effect (ES) is positive and significant ($p<0.05$), indicating that this increases firm's value added. The estimated relationship between the interaction term and productivity is also significant ($p<0.05$) and positive (model III). Additionally, the increase in R^2 from model II to model III is highly significant ($p<0.01$) indicating a moderating effect from environmental spillover.

Diagnostic tests for serial correlation, functional form, normality of the error terms, and heteroscedasticity indicate acceptance of the null hypothesis at the 0.05 level of significance for the three estimated models.

In order to assess the incidence of environmental variables on the efficiency of each firm, the individual fixed effects and the normalised technical efficiencies are estimated. The distribution of these estimated is showed in Fig. 1, obtaining a sample mean efficiency of 0.59. The results of regression, according of Eq. (9) are shown in Table 4.

[13] In analyses of the industrial sector from different countries (USA, France, Japan...), this parameter is about 0.3 (e.g. Griliches and Mairesse, 1984; Wakelin, 2001). In the case of Spain, for instance, Raymond (1989) obtains an elasticity of 0.389, on consolidated data in the country economy.

The results show that physical capital (C) is positively related to individual efficiency ($p<0.01$). In a relative sense, the estimated parameter value may complement the one obtained previously (model III). If we consider the sum of both, 0.348 (as the addition of the temporal variability and the individual fixed effect obtained with models III and VI), this approaches the values obtained in previous studies (e.g. Wakelin, 2001). The coefficient of labour variable (*L*) is positive but not significant in model VI.

The EP variable has a positive and significant impact on managerial efficiency considering the three models (IV, V and VI), although this impact is less than the effect on productivity obtained previously. The whole impact (temporal variability and firm's fixed effect) reaches a value of 0.157, considering the complete models III and VI. This value can be considered relatively high in comparison with other related studies (e.g. Céspedes-Lorente and Galdeano-Gómez, 2004), but this may be associated with the firms' adaptation to new environmental requirements, as previously indicated.

Considering the variables related to environmental spillovers, we observe a positive and significant spillover direct effect (ES), improving the estimation's efficiency (from model

Table 3 – Within Group (WG) estimations (fixed effects model)

Dependant variable: ln VA	Model I	Model II	Model III
ln *C*	0.358^{***}	0.291^{***}	0.236^{***}
	(4.108)	(3.183)	(2.460)
ln *L*	0.069^{**}	0.063^{**}	0.057^{**}
	(1.870)	(1.946)	(1.725)
$(EP)^{1/2}$	0.122^{***}	0.108^{***}	0.098^{***}
	(2.704)	(2.651)	(2.483)
$(ES)^{1/2}$	–	0.087^{**}	0.084^{**}
		(1.976)	(1.896)
$(EP)^{1/2}(ES)^{1/2}$	–	–	0.073^{**}
			(1.861)
Dummy temporal variables	Included	Included	Included
R^2 (adjusted)	0.741	0.798	0.861
ΔR^2	–	0.057	0.063
F-test for ΔR^2	–	4.106^{**}	5.856^{***}
Observations	558	558	558
Serial correlation [a]	0.173	0.361	0.386
	$\chi^2(3)=4.98$	$\chi^2(3)=3.21$	$\chi^2(3)=3.04$
Functional form [b]	0.291	0.370	0.422
	$\chi^2(1)=1.12$	$\chi^2(1)=0.80$	$\chi^2(1)=0.65$
Normality [c]	0.526	0.593	0.587
	$\chi^2(2)=1.29$	$\chi^2(2)=1.05$	$\chi^2(2)=1.07$
Heteroscedasticity [d]	0.381	0.472	0.491
	$\chi^2(1)=0.76$	$\chi^2(1)=0.51$	$\chi^2(1)=0.47$

Note: *t*-tests are reported in parentheses. $^{***}p<0.01$; $^{**}p<0.05$; $^{*}p<0.10$.

Results of diagnostic tests are shown as *p*-values and the correspondent chi-squares below.

[a] Lagrange multiplier test of residual serial correlation using 3 lags length (based on Akaike information criteria).

[b] Ramsey's reset test using the square of the fitted values.

[c] Jarque–Bera normality test.

[d] Based on the regression of squared residuals on squared fitted values.

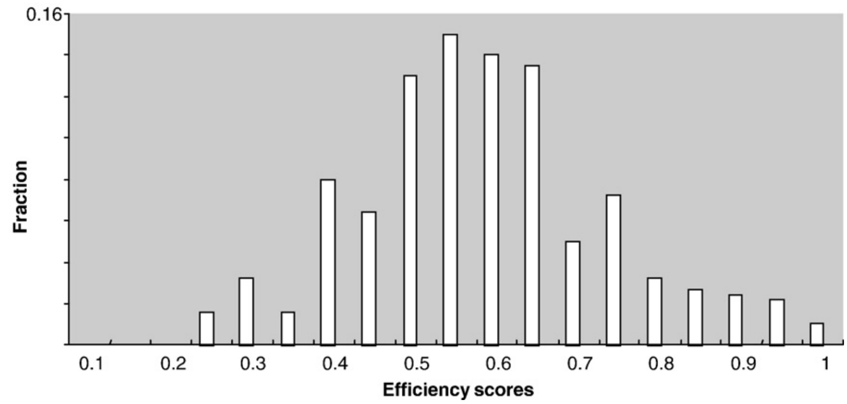

Fig. 1 – Distribution of technical efficiency.

IV to model V). The estimations of model VI indicate that the inclusion of spillover indirect effect also improves the coefficient of determination, although the impact (in terms of parameter significance) is relatively low in comparison with productivity estimations. Thus, we can deduce that the moderation effect of environmental spillover has more impact on value added (productivity) than on individual efficiency, which can be partially affected when a greater intensification of environmental expenditure takes place in the sector. The incidence of competitive interactions, with negative and significant parameters, is revealed as a determinant of efficiency in the presence of spillover effects, i.e. a greater value of the derived HH index (and thus, less degree of competition in the market) implies less firm efficiency. Size has significant coefficients, indicating a positive incidence on efficiency, while age presents non-significant parameters.

Diagnostic tests in Table 4 suggest the non-existence of residual serial correlation, and problems related to functional form, normality and heteroscedasticity for the estimated models IV, V and VI.

5. Discussion and conclusions

The present work uses the concept that spillover effects are applied to assess the ability of investment in environmental practices to influence firms' productivity and efficiency.

Our study contributes to the literature on industrial agglomeration and geographical clusters, establishing a relationship between spillover effects and organisational competitiveness. It also extends many of the assumptions on this type of agglomerations related to their ability to disseminate green practices linked to innovation among companies. Our results show that another type of practices, environmental ones, can also be spread locally in the industry and can generate competitive advantages on the individual company level.

There are some limitations to this study which may encourage further work. One of these is its focus on a single industry in a given geographical area, which affects the generalisation of the findings. Although other researches works have studied the dissemination of innovation capabilities by the spillover effects in different industries (Audretsch and Feldman, 1996), researches should interpret these results with care when extrapolating them to other organisational contexts, with different levels of uncertainty and different regulatory, competitive and technological conditions. As

Table 4 – Technical efficiency regressions

Dependant variable: TE_i	Model IV	Model V	Model VI
Constant	1.232***	1.083**	1.017**
	(2.851)	(2.072)	(1.982)
ln *C*	0.207***	0.132***	0.112***
	(3.011)	(2.530)	(2.596)
ln *L*	0.053*	0.046*	0.024
	(1.620)	(1.643)	(0.855)
$(EP)^{1/2}$	0.079***	0.063**	0.059***
	(2.618)	(2.641)	(2.528)
$(ES)^{1/2}$	–	0.035**	0.032**
		(1.891)	(1.872)
$(EP)^{1/2}(ES)^{1/2}$	–	–	0.029*
			(1.671)
Competition index	−0.073**	−0.065**	−0.058**
	(−2.315)	(−2.104)	(−1.927)
Age	0.034	0.028	0.025
	(1.269)	(0.847)	(0.812)
Size	0.061**	0.046**	0.031*
	(2.026)	(1.815)	(1.718)
R^2 (adjusted)	0.558	0.636	0.669
ΔR^2	–	0.078	0.033
F-test for ΔR^2	–	4.297**	2.886*
Observations	62	62	62
Serial correlation [a]	0.276	0.249	0.281
	$\chi^2(2)=2.58$	$\chi^2(2)=2.72$	$\chi^2(2)=2.54$
Functional form [b]	0.418	0.453	0.507
	$\chi^2(1)=0.65$	$\chi^2(1)=0.56$	$\chi^2(1)=0.44$
Normality [c]	0.329	0.397	0.383
	$\chi^2(2)=2.22$	$\chi^2(2)=1.85$	$\chi^2(2)=1.92$
Heteroscedasticity [d]	0.632	0.702	0.721
	$\chi^2(1)=0.22$	$\chi^2(1)=0.14$	$\chi^2(1)=0.12$

Note: *t*-tests are reported in parentheses. ***$p<0.01$; **$p<0.05$; *$p<0.1$. Results of diagnostic tests are shown as p-values and the correspondent chi-squares below.

[a] Lagrange multiplier test of residual serial correlation using 2 lags length (based on Akaike information criteria).

[b] Ramsey's reset test using the square of the fitted values.

[c] Jarque–Bera normality test.

[d] Based on the regression of squared residuals on squared fitted values.

pointed out by Beise and Rennings (2005), the firm's motivations for eco-innovating may be different depending on the character of the good or industry; for instance, while biological food creates benefit for both the firm and the natural environment, the consumption of conventional products, such as electricity from renewable energy, has no additional private benefits. Another future research line, from the methodological point of view, would be a more general modelling of the production function including spillover effects and their diffusion process among firms.

For public administrations, this article suggests the importance of encouraging environmental awareness and competitive resources on a local or regional level. It also highlights the importance of encouraging spillovers effects by means of tools such as contact networks, business associations the transfer of qualified staff among organisations, or the companies' capacity to imitate (Malmberg and Maskell, 2002).

Based on the results, the stock of a firm's investments in environmental practices is positively related to its performance (value added), supporting studies on the same issue in other industries (Klassen and Whybark, 1999) and in the food industry in particular (Nijkamp and Vindigni, 2002). They also confirm that total industry investment in environmental practices in the region is positively related to an individual firm's performance, obtaining empirical evidence of the influence of spillover effects on competitiveness. Finally, empirical evidence has also been obtained showing that total investment in the sector on environmental practices has a slight but significant bearing on the relationship between firm-level investment in environmental practices and performance.

Our findings regarding of spillover effects within the industry, and therefore outside the company, which help to generate competitive advantages based on environmental efficiency, have major implications.

The relationship between spillover processes and the development of environmental practices represents a major contribution to research into environmental management. Different authors have identified the source of this environmental productivity as regulatory pressure, stakeholder pressure, the firm's innovation capabilities, or networks (e.g. Mazzanti and Zoboli, 2006). We further this line by including the effects of industrial agglomeration as an influence on the process of acquiring environmental capabilities.

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Appendix A

The adoption of generalised functional forms (generalised translog or Generalised Leontief) implies dealing with additional variables (in our model: EP and ES) as usual inputs of the production function as follows: $Y=F(X, \text{EP}, \text{ES})$, Y being the vector of output and X the vector of ordinary inputs.

Besides this assumption about environmental components (which does not agree with our supposition about KE decomposition, according to the specifics of our empirical setting), an excessive parametrisation of functional form implies greater complexity when interpreting results, particularly as regards spillovers effects (e.g. Griliches and Mairesse, 1998). The usual approach followed is an augmented production function (in most cases Cobb–Douglas specifications) with additive separability. In our case, this is specified as follows: $Y=F(X)+f(\text{EP}, \text{ES})$.

Recently, Girma et al. (2005), in modelling FDI spillovers, use a translog specification maintaining this additive separability. Considering this approach, we can obtain the following functional form:

$$\ln Y = \beta_0 + \Sigma_j \beta_j \ln X_j + 1/2 \Sigma_j \Sigma_k \beta_{jk} \ln X_j \ln X_k + \gamma_{\text{ep}} \ln \text{EP} + \gamma_{\text{es}} \ln \text{ES} + 1/2 \gamma_{\text{eps}} \ln \text{EP} \ln \text{ES} + d_t + \varepsilon$$

This also allows us to estimate direct and indirect spillover effects. The estimation of this model offered similar results to model III (Table 3), obtaining for environmental knowledge parameters the following: $\gamma_{\text{ep}}=0.107^{***}$; $\gamma_{\text{es}}=0.072^{**}$; $\gamma_{\text{eps}}=0.065^{**}$. The log-likelihood ratio test for H_0: $\beta_{jk}=0$ (all j, all k) showed that the null hypothesis cannot be rejected at 5% significance, indicating in this case the similarity with the Cobb–Douglas specification.[14]

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[14] Girma et al. (2005) also obtain similar results to an augmented Cobb–Douglas estimation.

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