Why is environmental performance different between firms?

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ABSTRACT.- Environmental performance is a major matter of concern for both policy-makers and firms' managers. In this paper, we interpret firms' environmental performance as their ability to reduce polluting wastes while maintaining observed levels of inputs and desirable outputs. Making use of Data Envelopment Analysis techniques, we compute waste-specific environmental efficiency measures for a sample of ceramic tile producers located in the eastern Spanish region of Valencia. Our results show that there exists substantial room for improving environmental performance with highly beneficial consequences for the local environment. In a second stage of our analysis, we find that affiliation to the regional Technological Institute ITC, aimed at promoting technological innovation within the ceramic tile industry, improves tile firms' environmental efficiency. Besides, firms located in the local industrial district of the Plana Baixa enjoy what we have broadly defined as 'environmental spillovers', which enhance their environmental performance. Also, ceramic tile firms outsourcing the management of wastes show better environmental performance.

KEYWORDS: environmental performance; efficiency; tile industry; environmental spillovers; DEA; bootstrapping.

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1.- Introduction.

Environmental performance and the impact of firms' productive activity on the environment are receiving increasing attention from both policy-makers and academics in the field of environmental economics. Furthermore, environmental issues are also becoming a major matter of concern for firms managers. The growing recognition of the environment as a public good in the industrialised countries has stimulated wide-ranging legislation aimed at achieving predetermined standards of environmental quality. Accordingly, firms face increasing environmental legislation aimed at bringing under control their emission of harmful wastes, which for a long time was considered an external interference with firms' economic activity. Nevertheless, some firms' managers have recently realised that taking the lead in environmental behaviour could bring them important benefits, helping to enhance firms' brand image and market share. Firms' awareness of environmental issues is also being stimulated by the European Union authorities, in the context of a wider debate recently opened about *corporate social responsibility*, a concept whereby companies decide voluntarily to contribute to a better society and a cleaner environment (European Commission, 2001).

In view of the increasing impact of economic activity on the environment and the rising awareness of environmental concerns, over the past two decades economic literature has taken a growing interest in the assessment of firms' environmental performance and the valuation of the impact on productive activity of public environmental-friendly regulations (Tyteca, 1996 and Allen, 1999 review the literature). In measuring environmental performance several approaches have been followed. A number of papers have focused on adapting the conventional indices of productivity measurement to the presence of *undesirables* in the production processes. One of the earliest papers in this line of research was that by Pittman (1983) who computed some productivity indices accounting for both desirable outputs and wastes, previously valued by their shadow prices. Other articles in this line are Färe *et al.* (1993), Coggins and Swinton (1996), Swinton (1998) and Reig-Martínez *et al.* (2001). Moreover, Chung *et al.* (1997) developed a *Malmquist-Luenberger* productivity index that credits producers for simultaneously increasing the production of desirable outputs while reducing the production of *undesirables*, also allowing the change in *Total Factor Productivity* to be decomposed into changes in efficiency and technical change. Subsequent papers in a similar line of research are Färe *et al.* (2001), Jeon and Sickles (2004), Domazlicky and Weber (2004) and Barla and Perelman (2005).

Some other papers have extended the traditional analysis of efficiency pioneered by Farrell (1957), by developing efficiency measures that explicitly take into account the existence of *undesirables*. In a pioneering paper, Färe *et al.* (1989) established the basis for this extension by considering different technological assumptions as to the disposability of good and bad outputs (wastes). Furthermore, they proposed several indicators capable of assessing the impact on firms' performance of environmental regulations aimed at achieving standards of environmental quality by reducing the production of polluting wastes. Afterwards, Färe *et al.* (1996) used distance functions to develop several indicators of efficiency considering that expanding good outputs can be hampered by environmental restrictions on the production of contaminating wastes (see also Tyteca, 1997). More recently, directional distance functions (Chambers, 1998; see also Färe and Grosskopf, 2000, 2004) have been developed as adequate tools to approach economic and environmental performance issues in an integrated fashion (Picazo-Tadeo *et al.*, 2005).

Besides the large number of empirical studies carried out within this field of research, in most of them the emphasis is on measuring productive efficiency including in the analyses unwanted wastes that come with the production of desirable outputs. Nevertheless, few attempts have been made to define and quantify the concept of *environmental efficiency*. In this paper, we make use of non-parametric *Data Envelopment Analysis* techniques to compute waste-specific environmental efficiency scores for a sample of ceramic tile producers located in the eastern Spanish region of Valencia. Environmental efficiency is interpreted here as the ability of a firm to reduce its polluting wastes while maintaining its currently observed levels of inputs and desirable outputs. In a second stage of our research, we associate environmental efficiency with several characteristics of firms related to their management of wastes or geographical location, among other features. In general, we obtain low scores of environmental efficiency, revealing the existence of substantial room for improving environmental performance, with wide potential benefits for the local environment where tile firms are located. Likewise, differences among firms are found to be important. In addition, we discover that the regional Technological Institute *ITC*, which aims to promote technological innovation and best practices among ceramic tile firms, enhances the environmental efficiency of associated firms. Moreover, environmental performance is higher for firms located in the *Marshallian* type industrial district of the *Plana Baixa*, and also for firms using external services to manage wastes.

Our paper contributes to the current strand of literature in several directions. First, the debate in the industrialized countries about environmental concerns calls for methods of evaluating firms' environmental performance, and this is one of the points that our paper emphasises. Second, the paper contributes empirical evidence concerning the relationship between environmental performance and some firms' features and environment variables. Beyond their academic interest, these findings might provide policy-makers with meaningful information to improve the design of environmental policies. Third, from a conceptual perspective, we suggest the hypothesis that traditional *Marshallian* externalities could also be including what we refer to as *environmental spillovers*.

The remainder of this paper is organised as follows. Section two deals with methodological issues. Section three describes the data. Section four explains the empirical findings and discusses their implications for environmental and regional policies. Finally, section four concludes.

2.- Methodological issues.

In order to describe the main insights of the methodology, let us start by considering a productive process that transforms a vector *x* of n = 1,...,N inputs into a vector *y* of m = 1,…,M desirable outputs. Transformation of inputs into desirable outputs generates a set *w* of h = 1,...,H polluting wastes, which are considered to be undesirable outputs. Furthermore, it is also assumed that the *technology* is given by:

$$T = \left[(x, y, w) : x \text{ can produce } (y, w) \right] \tag{1}$$

This technology of reference provides a complete description of all technologically feasible productive plans, i.e., relationships between inputs, desirable outputs and contaminating wastes. The technology can likewise be modelled through the *output set*, which represents all the output vectors (*y,w*) attainable from a given vector of inputs *x*, and is formally defined as:

$$P(x) = \left[(y, w) : (x, y, w) \in T \right] \tag{2}$$

It is assumed that the output set has the standard properties initially suggested by Shephard (1970) (see also Grosskopf, 1986). These properties include the axioms of possibility of inaction, no free lunch, free disposal of desirable outputs and strong disposability of inputs. It is also assumed that the output set is a convex compact set. Furthermore, we consider that there exists null-joint production and that outputs (both desirable and undesirable) are weakly disposable.

Null-jointness was first introduced by Shephard and Färe (1974) to model the idea that good and bad outputs are jointly produced. This assumption means that if no bad outputs are produced then none of the good outputs are produced. Likewise, if some good outputs are produced, some quantity of undesirable outputs must also be produced. Formally, *null-jointness* is defined as:

$$(y, w) \in P(x);\ w = 0 \Rightarrow y = 0 \tag{3}$$

Weak disposability of outputs was proposed by Färe *et al.* (1989) as a sensible way to model the idea that reducing *bads* may not be a costless activity (as traditional production theory conventionally considers) but involves a cost, measurable as a reduction of the production of *goods*. In other words, when firms have to divert *productive* resources, i.e., resources that otherwise could be devoted to producing desirable outputs, to reduce undesirable outputs, the production of *goods* will necessarily be reduced. The axiom of *weak disposability of outputs* can be formally expressed as:

$$\left(y,w\right) \in P\left(x\right);\ 0 \le \beta \le 1 \Rightarrow \left(\beta y,\beta w\right) \in P\left(x\right) \quad (4)$$

In this paper, our interest lies in calculating potential waste-specific reductions that could result in achieving environmental efficiency, i.e., measures of firms' waste-specific environmental efficiency. In order to do this, we make use of Russell's measure of efficiency, initially proposed by Färe and Lovell (1978) and extended by Färe *et al.* (1983) (see also Zieschang, 1984). Specifically, we integrate Russell's non-proportional measure of efficiency into the traditional approach to incorporating environmental externalities into efficiency measurement. Based on the above characterisation of the technology, for positive wastes our measure of environmental efficiency is defined as:

$$\textit{Waste-specific EEM}\ \left(x,y,w\right) = Inf\left[\frac{1}{H}\sum_{h=1}^{H}\theta_h : \left(y,\theta_1 w_1,...,\theta_H w_H\right) \in P\left(x\right)\right] \quad (5)$$

θ_h being a positive parameter that measures environmental efficiency in polluting waste h.

This efficiency measure searches for the maximum attainable reduction of each undesirable output conditioned to given levels of desirable outputs and inputs, so that the resulting productive plan remains within the output set or set of technologically feasible productive plans. A significant advantage of this measure of environmental efficiency is that it has a really simple economic interpretation: a firm will be considered environmentally inefficient if it can reduce its polluting wastes for a given combination of inputs and desirable outputs. In addition, the non-proportional nature of the Russell approach to efficiency measurement allows us, as noted, to compute a set of scores of waste-specific efficiency instead of a single radial measure of environmental efficiency. This is also a remarkable feature for several reasons. On the one hand, firms' environmental efficiency measures computed at the waste level could offer valuable information to firms' managers, because the impact on the environment and the danger may be different from one waste to another. On the other hand, computing specific scores of environmental efficiency for each undesirable output permits us to test for the possible existence of differences among wastes in the factors explaining firms' environmental efficiency.

Figure 1 provides a graphic illustration of our measure of environmental efficiency. This graphic portrays the output set $P(x)$ in the space of desirable output y and undesirable output w_h, conditional on the observed level of inputs x. Under the set of assumptions made regarding the technology, the output set is bounded by the segment *OABCD* and the x-axis back to the origin. For a firm producing in the interior of the output set, e.g., productive unit k, it could be possible to move towards a more environmentally-friendly production plan that enables it to produce less undesirable output while maintaining the same amount of desirable output and inputs. The measure of environmental efficiency of firm *k* would be computed as the quotient between its production of polluting wastes under efficient and observed productive plans, i.e., ratio Ow^{*}_{h}/Ow_{h}.

Insert Figure 1

Our choice here for computing environmental efficiency scores is to make use of goal programming techniques and non-parametric *Data Envelopment Analysis*. *DEA* techniques were introduced by Charnes *et al.* (1978) in a pioneering paper that used mathematical programming to pursue Farrell's approach to efficiency measurement (Farrell, 1957). The mathematical programming approach to modelling production technology and producer behaviour provides "*... an elegant way of simultaneously constructing frontier technology from data and calculating the distance to that frontier for individual observations or activities*" (Färe *et al.*, 1994, p. 11). *DEA* presents notable advantages over the econometric approach to efficiency measurement. On the one hand, it permits us to construct the frontier representing best practices without imposing a parametric functional form on technology or on deviations from it (inefficiencies). On the other hand, it allows the construction of a *surface* over the data that permits the comparison of one production method (or best producer) with the others, in terms of a performance index. In other words, *DEA* provides a very simple way to calculate the environmental efficiency gap that separates one producer's behaviour from environmentally efficient productive practices. Further details on *DEA* can be found in Cooper *et al.* (2004).

In order to empirically compute our measures of environmental efficiency, let us consider that we observe a sample of k = 1,...,K decision-making units. For firm *k'*, waste-specific scores of environmental efficiency arise as the solution of the following goal programming problem:

$$\begin{aligned}
&\text{Waste-specific EEM}\left(x^{k'},y^{k'},w^{k'}\right)=Min_{\theta_h^{k'},z^k}\ \frac{1}{H}\sum_{h=1}^{H}\theta_h^{k'} \\
&\text{subject to:}\quad x_n^{k'}\geq\sum_{k=1}^{K}z^k x_n^k \qquad n=1,\ldots,N \qquad (i)\\
&\qquad\qquad\quad y_m^{k'}\leq\sum_{k=1}^{K}z^k y_m^k \qquad m=1,\ldots,M \qquad (ii)\\
&\qquad\qquad\quad \theta_h^{k'}w_h^{k'}=\sum_{k=1}^{K}z^k w_h^k \qquad h=1,\ldots,H \qquad (iii)\\
&\qquad\qquad\quad z^k\geq 0 \qquad k=1,\ldots,K \qquad (iv)
\end{aligned}\tag{6}$$

z^k being a set of intensity variables that determines the weightings of each observed decision-making unit in the composition of the technological frontier. Constant returns to scale have also been imposed (see Banker *et al.*, 1984).

In program (6), the set of constraints in (*i*) guarantee that at the optimum, firm *k'* will make use of no less inputs than the efficient productive plan it is compared with. Restrictions in (*ii*) ensure that under its environmentally efficient production plan, decision-making unit *k'* produces no more desirable outputs than the technological reference at the frontier. Furthermore, the inequality constraints on the good outputs side imply that these outputs are freely disposable. Together with the strict equality constraints on the bad outputs side in (*iii*), good and bad outputs are weakly disposable. Finally, the model satisfies null-jointness provided that (see Färe and Grosskopf, 2004):

$$\sum_{k=1}^{K} w_h^k > 0 \qquad h = 1,\dots,H \tag{7}$$

$$\sum_{h=1}^{H} w_h^k > 0 \qquad k = 1,\dots,K \tag{8}$$

Condition (7) implies that every undesirable output is produced by at least one productive unit, while condition (8) means that each firm produces at least one undesirable output[1].

3.- Data description.

In this paper we use a cross-section dataset of eighteen ceramic tile producers located in the eastern Spanish region of Valencia. This region is the major Spanish producing and exporting area, accounting for over 95 per cent of ceramic tile production. Furthermore, tile firms are highly concentrated in the province of Castellón, around a small number of areas that could be broadly considered local industrial districts, in the sense given to this expression by the literature on economic geography, the *Plana Baixa* district being the most important one. The data were gathered from the information available in the *Valencian Community Inventory of Industrial Residues* drawn up in 1995 by the *Department of the Environment* of the *Valencian Regional Government*.

[1] To further illustrate the relationship between null-jointness and these conditions, let us assume, for firm *k'*, that each bad output in (6)-(*iii*) is equal to zero. In that case, because of conditions (7) and (8) each intensity variable must be zero, implying that every desirable output in (6)-(*ii*) must also be zero.

All firms share a homogeneous productive process, producing ceramic tiles by the use of one intermediate input, consisting of clay, kaolin, felspar and limestones, and two primary production factors, labour and capital. Additionally, the production of tiles generates two polluting wastes: watery mud, which is a highly contaminating discharge specific to the tile industry, and used oil. Output is measured in square meters of ceramic tiles. Labour and capital are proxied by the number of workers and energy consumption in kilowatts/hour, respectively, while the intermediate input is measured in tons. Finally, watery mud and used oil are measured in tons and kilograms, respectively. This dataset was also used by Reig-Martínez *et al.* (2001) to compute shadow prices for wastes making use of standard output distance functions. Additionally, Picazo-Tadeo *et al.* (2005) made use of the same source of data to assess the impact of environmental regulations on tile firms' performance by means of an indicator computed using directional technology distance functions. *Table 1* shows some descriptive statistics for the data.

Insert Table 1

This dataset presents, in our view, a couple of remarkable features that enhance its usefulness to perform the type of analysis we carry out in this paper. On the one hand, output, inputs and contaminating wastes are measured in physical units, which facilitates the economic interpretation of our measures of environmental efficiency. Besides, all data were recorded at the productive process level, allowing us to perform more accurate comparisons among homogeneous productive plans. Even more, in the process of information collection, tile firms using two or more productive processes were asked to inform separately of outputs, inputs and wastes corresponding to each homogeneous productive process. On the other hand, apart from detailed data on desirable output, inputs and polluting residues, our source of data provided us with a wide set of information on firms' management of wastes, spatial location and other interesting features. This circumstance has allowed us to perform a second stage analysis where environmental efficiency scores have been related to some of these firms' characteristics. Conversely, the small number of firms in our sample makes it difficult to perform other additional analysis that could enhance the robustness of our results.

4.- Empirical findings, discussion and policy implications.

In this section, we present and discuss our estimates of environmental performance. For each ceramic tile firm in the sample, waste-specific environmental efficiency indices have been worked out by solving program (6). All programs have been written and solved using

GAMS software. Averages of the computed scores of environmental efficiency are presented in *Table 2.* Before interpreting our results, it should be highlighted that efficiency is a relative concept, i.e., the efficiency is only as good as the best in the sample. Accordingly, our scores of environmental efficiency should be interpreted as measures of *relative efficiency*, as they are computed comparing each tile firm in the sample with tile firms showing the best observed environmental performance.

Insert Table 2

Our results suggest that substantial reductions in polluting wastes could occur, with great accompanying benefits for the environment. Concerning watery mud, the waste-specific environmental efficiency score is 0.633, indicating, on average, a 36.7 per cent maximum feasible reduction of this polluting waste, while maintaining inputs and desirable outputs. Likewise, the average maximum attainable reduction for used oil reaches 21.2 per cent, i.e., the score of environmental efficiency in used oil is 0.788. Furthermore, computed scores of environmental efficiency vary appreciably across tile firms. The most inefficient firm could reduce its production of watery mud by 95 per cent by achieving environmentally efficient behaviour, and the potential reductions of this polluting waste for some other tile firms in the sample are also substantial. Differences in environmental efficiency among firms become smaller with regard to used oil.

The wide range of computed scores of environmental efficiency in watery mud should not come as a surprise, given the wide range of methods employed within the Spanish tile industry to deal with this polluting waste. When the data were collected, firms using modern methods to manage and recycle watery mud coexisted with other tile firms that were really unconcerned about environmental pollution caused by this waste. Furthermore, our results here are consistent with those of Reig-Martínez *et al.* (2001). This paper computed shadow prices for watery mud and used oil making use of our same dataset, and found substantial differences among firms. It was suggested that higher shadow prices for undesirable outputs could correspond to firms that had already reached a high environmental performance and, consequently, would face a higher marginal cost if they stepped-up their efforts to reduce waste discharges. Conversely, lower shadow prices would correspond to tile firms employing methods and equipment less adapted to recycling wastes or minimising their delivery. Our results here lend empirical support to that hypothesis, as shown by the positive coefficients of correlation between the absolute value of shadow prices computed by Reig-Martínez *et al.* (2001) and our waste-specific measures of environmental efficiency. The correlations are 0.36 for watery mud and 0.13 for used oil.

DEA is a deterministic approach to efficiency measurement whose results tend to be sensitive to outliers and measurement errors, particularly if these observations are shaping a portion of the efficient frontier. With the aim of testing the influence of this potential problem in our estimates of environmental efficiency, we have verified that five decision-making units in the sample *envelop* two or more times the environmental behaviour of other firms. Consequently, our results do not depend on a single firm that repeatedly envelops other firms, but rather on a set of efficient firms. In addition, we have performed a sensitivity test that shows that the results changed very little after running the analysis removing the five tile firms shaping the frontier one at a time.

In order to go further into our analysis, we have computed the quotient between polluting wastes and output, as a measure of wastes intensiveness, under both currently observed and environmentally efficient production plans. Considering the aggregate output and wastes of the eighteen tile firms in our sample, 1,432 tons of watery mud per million square meters of ceramic pavement are dumped into the local environment under observed production plans, and 641 tons under firms' environmentally efficient production plans. Regarding used oil, wastes generated are 897 and 791 kilograms per million square meters produced under observed and environmentally efficient productive plans, respectively. Consequently, contaminating wastes generated per unit of output could be substantially reduced by achieving environmental efficiency, with wide beneficial consequences for the environment.

Making use of different methodological approaches, several studies have suggested that there exist highly significant differences concerning environmental performance, even when the comparisons refer to decision-making units. As noted, our estimates of environmental efficiency also range widely. Thus, in a second stage of our research we have tried to ascertain if some firms' characteristics or other environment variables could be related with the differences in environmental performance among firms.

There is no formal theory as to what the determinants of firms' environmental performance should be. Tyteca (1997) established three broad classes of factors that could explain firms' differences of environmental efficiency, which referred to the economic context, *X-inefficiency* and technological aspects. The economic context includes external factors such as lack of environmental regulations or certain schedules of taxes, that help to explain why environmental concerns are not among the major priorities of firms' managers. The concept of *X-inefficiency* designates any inefficiency that can not be handled in the scope of the neo-classical production theory (see Liebenstein, 1978). Finally, regarding technological aspects, the production processes compared can be different, even if they are designed to transform the same inputs into the same outputs, e.g., for the purpose of explaining environmental performance, older capital goods are likely to be less efficient than newer equipment. Concerning our research, the factors which according to our hypothesis affect environmental efficiency are drawn from previous studies and from our own beliefs regarding these factors in the particular case of the Spanish ceramic tile industry. Obviously, for practical reasons, the set of explanatory variables we include in our second stage analysis is also conditioned by the availability of statistical information. The variables analysed are described in *Table 3*, which also reports the averages of firms' computed waste-specific environmental efficiency measures according to their characteristics.

Insert Table 3

In the empirical literature in the field of efficiency measurement, it has been habitual to perform two-stage analyses to investigate, in the second stage, the determinants of firms' efficiency scores obtained in the first stage. In performing the second stage, two primary methodological approaches have been followed. The first one involves grouping firms according to their computed efficiency indices and checking for statistically significant differences among groups in some specific variables that are likely to affect efficiency, e.g., using non-parametric tests of hypothesis. The second approach uses regression analysis, e.g., censored Tobit regression or ordinary least squares after transforming estimates of efficiency, to test for the relationship between efficiency and some covariates representing environmental variables. Nonetheless, Simar and Wilson (2005) show that second-stage analyses based on regressing first-stage *DEA* efficiency estimates against a set of explanatory variables may lead to wrong results, mainly because of the serial correlation of the first-stage *DEA* estimates and the correlation between the error term and the set of covariates in the second stage. Instead, truncated regression and bootstrapping procedures are proposed to allow for better estimation and statistical inference in second-stage analyses.

In our manuscript, a number of hypotheses have been tested using truncated regression analysis and confidence intervals computed according to the single bootstrapping procedure designed by Simar and Wilson (2005) to improve on inference[2]. In order to accommodate our analysis to the left-truncated distribution functions developed by this paper, in our second-stage regressions the dependent variable is always the inverse of the first-stage *DEA* estimates of environmental efficiency. This transformed variable ranges, in consequence, from

[2] Given that the aim of our manuscript is eminently applied, we refer readers to the original paper for methodological details on this approach to second-stage analyses.

one to infinity[3]. Furthermore, the number of replications in the bootstrap procedure has been settled equal to 1000. *Tables 4* and *5* display the estimated parameters (column 1) and their confidence intervals computed according to Simar and Wilson (columns 2 to 5), for watery mud and used oil, respectively.

Our two primary hypotheses are referred to as the *technological hypothesis* and the *geographical hypothesis*. Concerning the technological hypothesis, the dummy variable *affiliation to the Technological Institute ITC* (*Instituto Tecnológico de la Cerámica*) takes value 1 for firms associated to *ITC* and 0 otherwise. During the last two decades, the region of Valencia, where all the firms in our sample are located, has equipped itself with an innovation-fostering technological infrastructure that provides answers to the requirements of technological modernisation of the regional industry. As a part of this infrastructure, the region has a network of Technological Institutes specialised by branches of industrial production, *ITC* being the one concerned with the ceramic tile industry (see García-Reche, 2003 for details). These Institutes were promoted by the regional government during the eighties as non-profit entities under the form of free associations of firms in the same sector, and they are located close to the main centres of their respective industries. Institutes are oriented to stimulate technological innovation and diffusion of best practice, providing external services to associated firms such as project support and technological development, quality control of raw materials and end-products, or technical consulting, among other activities.

Insert Table 4

Association with the *ITC* is normally considered to be an indicator of innovative behaviour. In our sample, 5 out of 18 firms are affiliated to the *ITC*. Through its *Department of Environmental Quality*, the *ITC* permanently provides advice to associated firms' managers regarding the management of polluting wastes and other environmental concerns. Moreover, among other activities, it organises periodic meetings for affiliated firms to inform them about new technologies and developments concerning waste management in the ceramic tile industry. Our hypothesis is that affiliation should have a favourable effect on environmental

[3] With the purpose of illustrating the implications of this transformation in interpreting the results of our second-stage regression analysis, let us consider the following example. Let us assume that the score of environmental efficiency computed for, say, firm *k'* and watery mud is equal to 0.5. This means that the firm could maintain its levels of desirable output and inputs generating only fifty percent of its current level of waste. The inverse of this score, i.e., the variable to be used as dependent variable in our second regression analysis, is equal to 2, indicating that the firm is producing two times the quantity of watery mud that it should produce if it were environmentally efficient. In consequence, the larger the value of our transformed variable the smaller the firm's environmental efficiency.

efficiency because of the information that the *ITC* facilitates to its affiliates concerning access to new waste reduction techniques. The empirical results we obtain seem to confirm our hypothesis, as they allow us to assert with a confidence level of 99 per cent that affiliation to *ITC* has a positive and significant effect on tile firms' environmental performance in watery mud[4]. For lower confidence levels, e.g., 90 per cent, a positive relationship between affiliation and environmental efficiency in used oil in is also found.

The *geographical hypothesis* explores whether or not there exists a relationship between geographical location and environmental performance. As noted, the Spanish ceramic tile industry is highly concentrated around a small number of areas in the province of Castellón, the *Plana Baixa* being the largest of these local industrial districts. The *spatial location* variable is specified here to investigate our geographical hypothesis, and it takes value 1 if the firm is located in the district of the *Plana Baixa*, and 0 otherwise. Our guess is that the 8 firms (out of 18) located in this local industrial district enjoy a leading position that gives them rapid access to information released by suppliers of new industrial equipment and by competitors, facilitating the acquisition of better practices in dealing with industrial residues. In addition, close proximity should improve the chances of firms being more sensitive to good practice in terms of waste management.

Empirical evidence after performing the second-stage analysis reveals, with a 99 per cent confidence level, that spatial location statistically influences firms' environmental efficiency, and ceramic tile firms within the *Plana Baixa* industrial district show a significantly better environmental performance score than firms located outside this area. Furthermore, five of the six tile firms in our sample showing a really poor environmental performance in watery mud are situated outside of this industrial district. The relationship between environmental performance and spatial location could be picking up the existence of *environmental spillovers*, as a part of the external economies generated by the industrial district of the *Plana Baixa*. In our view, this could be a noteworthy result, since it suggests that beyond the classical *Marshallian* economies attributed to industrial districts, externalities also include environmental spillovers.

Moreover, in the particular case of the Spanish tile industry an additional explanation of our geographical hypothesis could be realistically argued. Industrial districts firms enjoy a

[4] Note that, because of the definition of the dependent variable as the inverse of the first-stage *DEA* estimates of environmental efficiency, a negative coefficient for affiliation to *ITC* implies, in fact, a positive relationship between environmental efficiency and affiliation. Exactly the same reasoning applies for the rest of the explanatory variables.

number of collective resources that, among other factors, include the participation of local institutions (Molina-Morales and Martínez-Fernández, 2004). According to current laws, the economic activity of Spanish tile firms is subject to environmental regulations legislated at the regional, national and also European level. However, the high concentration of the Spanish tile industry in a small number of municipalities within the *Plana Baixa* district, leads regional and local authorities, as well as other local institutions, to share a common concern about the impact of ceramic tile firms' productive activity on the local environment. The consequence of this concern is twofold. On the one hand, regional authorities take special care to make sure that tile firms located in the local industrial district of the *Plana Baixa* effectively comply with the environmental legislation in force. On the other hand, when it is lawfully possible, e.g., in managing watery mud waste, municipal authorities establish local environmental-friendly regulations that put additional pressure on tile firms to achieve better environmental behaviour.

Concerning *geography* and efficiency, some recent studies have also found a relationship between spatial location and technical (non-environmental) efficiency in the Spanish tile industry. Soler-Marco and Hernández-Sancho (2001) showed that tile firms located in the *Plana Baixa* district were, in general, more efficient technically than firms operating outside of that industrial district. Moreover, differences were found to be statistically significant. Furthermore, Hernández-Sancho and Soler-Marco (2002) pointed out that the higher technical efficiency of Spanish ceramic firms located in the district of *Plana Baixa* is mainly due to a more efficient use of labour.

In addition to technological and geographical variables, in our second stage regression analysis we have included the following explanatory variables: firm's size (measured by tile production in millions of square meters); environmental study carried out (dummy that equals 1 if the firm has carried out an environmental study of the impact of its activity on the local environment, and 0 otherwise); and, finally, external management of wastes (dummy variable that takes value 1 for firms using external services to manage polluting residues, and 0 otherwise).

Regarding the first of these variables, our results show that tile firms' size positively and significantly affects their environmental performance in used oil. In other words, the bigger the firm, the higher its environmental efficiency score. An attractive explanation for this outcome is to relate it to the existence of economies of scale in the management of wastes, which allow larger firms more profitably to replace old capital vintages by newer (and more expensive) technologies, able to reduce the pollution caused by tile production processes.

Nonetheless, we also believe that this result can be explained by the fact that bigger firms within the Spanish tile ceramic industry have realised that taking the lead in environmental performance can bring them important benefits, contributing to a better image in the eyes of both consumers and regulating authorities.

Moreover, in our empirical analysis we find that the last two variables included in the second stage regression, i.e., environmental studies relating to the impact of firms' productive activity on the local environment and management of contaminating wastes through external services firms, also positively and significantly influence ceramic tile firms' environmental performance in watery mud. In addition, outsourcing the management of wastes also improves environmental efficiency in used oil. On the one hand, regarding the first of these variables, our supposition is that tile firms that have made environmental studies concerning the impact of their productive activity on the environment (fifty per cent of the tile firms in the sample) are likely to have a greater awareness of environmental concerns, and this could explain their superior environmental performance. Besides, undertaking environmental studies permits firms' managers to achieve a better knowledge of the process of generation of contaminating residues and their costs, improving their skill in the management of wastes. Actually, in most cases, and particularly for larger tile firms, carrying out an environmental study constitutes a first step towards establishing an own department of environmental management.

On the other hand, regarding the relationship between external management of residues and environmental performance, our hypothesis is that outsourcing waste management (10 firms out of 18 in our sample employ the services of external firms to manage their wastes) also improves environmental efficiency because of the greater efficiency of external firms specialised in management and disposal of wastes. In fact, economic literature in other fields, e.g., agricultural economics, has repeatedly linked outsourcing with a managerial strategy of firms to achieve greater levels of efficiency. Furthermore, in the particular case of smaller ceramic tile firms, external waste management service firms play a role rather similar to that played by the *ITC*, advising small tile producers about new waste management techniques, and facilitating their adoption. Besides, many of these services firms are aware of the latest technologies in waste management through a direct and permanent contact with the *Department of Environmental Quality* of the *ITC*.

The ultimate purpose of our research is to try to bring economic analysis closer to the concerns of the policy-maker as regards policies affecting firms' environmental performance, particularly in the case of the Spanish ceramic tile industry. We consider that our research touches several issues of economic policy, especially at the regional government level. First, our results indicate that the Technological Institute *ITC* positively affects environmental performance, by improving the affiliated firms' chances of being more efficient environmentally. This outcome is in line with the findings of other empirical studies that have shown that the network of Technological Institutes developed in the eighties by the Valencian regional government has contributed to enhancing economic efficiency and performance in diverse manufacturing sectors (Hernández-Sancho *et al.*, 2000, Reig-Martínez *et al.*, 2001).

Second, spatial location also seems to matter as regards environmental performance. Beyond the classical *Marshallian* externalities attributed to industrial districts, our findings indicate that externalities also include *environmental spillovers*. Moreover, our belief is that the high concentration of the Spanish tile industry around a small number of municipalities in the industrial district of the *Plana Baixa* leads regional and local authorities to share a common concern about the impact of firms' production on the local environment, putting additional pressure on tile firms concerning their environmental performance. Third, supporting studies to assess the impact of ceramic tile producers on the local environment, and promoting external services firms dedicated to waste management, also emerge as suitable strategies for policy-makers to improve environmental efficiency.

Finally, our research also identifies several directions for further investigation. Although the Spanish ceramic tile industry is highly concentrated in the region of Valencia, it would be really interesting to perform additional analyses in other areas in order to substantiate or refute the findings of our paper. Similar studies of other manufacturing sectors could also be of interest. Besides, larger sample sizes and more detailed information and datasets would allow additional analysis to be performed, improving the robustness of our results.

4.- *Concluding remarks*.

The impact of productive activity on local environments is a major matter of concern for both policy-makers and firms' managers. The significant increase in laws regulating the emission of polluting wastes in the industrialised countries calls for methods of evaluating firms' environmental behaviour. Besides, detailed analyses of the specific variables influencing firms' environmental performance, supported by case studies or other empirical evidence, are also needed. In this setting, the aim of this paper is twofold. On the one hand, we use *Data Envelopment Analysis* techniques and non-radial efficiency measures to assess the environmental performance of a sample of ceramic tile firms located in the eastern Spanish region of Valencia. On the other hand, we perform a second-stage analysis to ascertain the influence of some firms' characteristics and other environment variables on individual tile firms' environmental efficiency.

The main findings of our research can be summarised as follows. Concerning environmental efficiency measurement, we find that there is substantial room for reducing polluting wastes, with wide potential benefits for the quality of the local environments where ceramic tile firms are located. Besides, differences among firms as regard their environmental performance are found to be important. In relation to our second concern, we have identified a set of variables influencing tile firms' environmental efficiency. First, as regards our *technological hypothesis*, we find that affiliation to the regional Technological Institute *ITC* positively and significantly affects environmental performance. Second, as to our *geographical hypothesis*, location also matters as a determinant of environmental performance. According to our results, ceramic tile firms located in the *Plana Baixa* industrial district enjoy what we have broadly defined as *environmental spillovers*, showing a better environmental performance than firms located outside that district. Finally, firms carrying out studies on the impact of their productive activity on the local environment and, also, firms managing their polluting wastes through external services firms, are likely to be more efficient environmentally.

In addition, we consider that our findings lead to some environmental policy conclusions, mainly at the regional government level. First, the Technological Institute *ITC* promoted by the Valencian regional government during the eighties has contributed to enhancing the environmental performance of ceramic tile firms. Second, geographical location also emerges as a variable capable of influencing environmental efficiency, and regional and local authorities can help to enhance the quality of the local environments where firms are concentrated by putting additional pressure on firms to comply with environmental regulations. Finally, supporting external services firms specialised in managing and disposing of polluting wastes emerges as an appropriate strategy for policy-makers to improve environmental efficiency.

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FIGURES AND TABLES

FIGURE 1.-
The output set in the space of desirable and undesirable outputs.

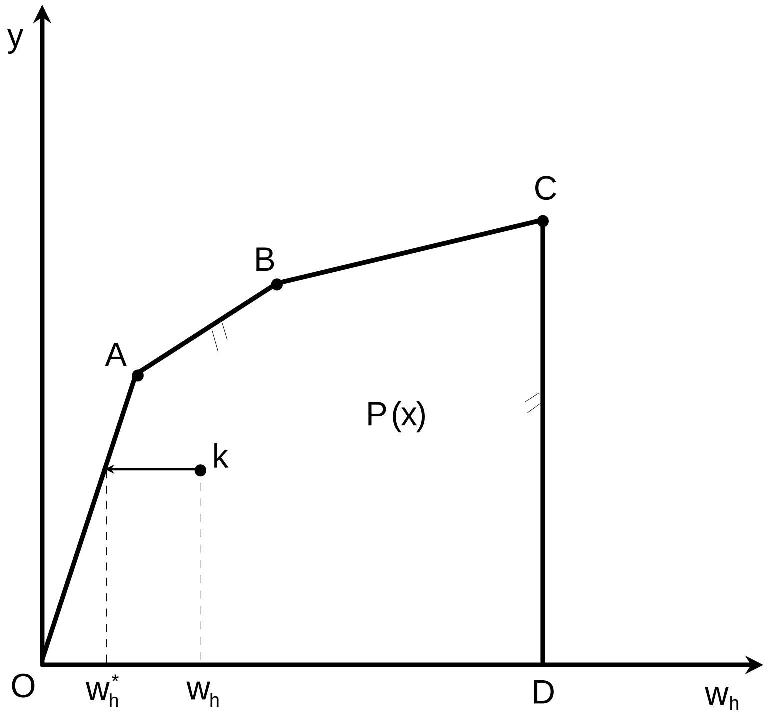

TABLE 1.-
Sample description.

	Measurement unit	Mean	Standard deviation	Maximum	Minimum
Desirable output					
Ceramic pavements	Square meters	2,031,077	1,168,311	4,500,000	200,000
Undesirable outputs					
Watery mud	Tons	2,908	4,108	15,648	14
Used oil	Kilograms	1,822	3,135	12,000	100
Inputs					
Clay, kaolin, felspar and limestones	Tons	50,192	40,762	144,000	3,300
Labour	Number of workers	128	121	428	25
Capital	Kilowatts/hour	4,573	4,705	20,000	500

TABLE 2.-
Computed scores of waste-specific environmental efficiency.

	Mean	Maximum	Minimum
Environmental efficiency in watery mud	0.633	1.000	0.050
Environmental efficiency in used oil	0.788	1.000	0.121

TABLE 3.-
Environmental efficiency according to firms' characteristics.

	Environmental efficiency in watery mud	Environmental efficiency in used oil
Affiliation to Technological Institute ITC		
Affiliated firms	0.821	0.965
Non affiliated firms	0.561	0.719
Spatial location		
Firms located in the *Plana Baixa* industrial district	0.761	0.785
Firms located outside of this industrial district	0.531	0.789
Firm's size		
Firms above the average sample size	0.710	0.717
Firms below the average sample size	0.572	0.849
Environmental study		
Firms that have carried out an environmental study	0.750	0.909
Firms that have not carried out an environmental study	0.517	0.666
External management of wastes		
Firms outsourcing waste management	0.662	0.861
Firms that do not outsource waste management	0.598	0.696

TABLE 4.-
Determinants of firms' environmental efficiency in watery mud. Truncated regression.

	Estimated parameter	Simar and Wilson confidence intervals			
		99 per cent level		95 per cent level	
		lower	upper	lower	upper
Constant	30.61	23.52	36.98	25.17	35.96
Affiliation to *ITC*	-8.56	-11.62	-5.16	-11.08	-5.87
Spatial location	-16.59	-17.93	-15.06	-17.75	-15.39
Firm's size	-1.66	-4.01	1.14	-3.61	0.47
Environmental study	-9.29	-14.10	-3.49	-13.38	-4.62
External management of wastes	-10.47	-15.29	-4.68	-14.57	-5.81
Sigma	0.627	0.534	1.216	0.612	1.200

TABLE 5.-
Determinants of firms' environmental efficiency in used oil. Truncated regression.

	Estimated parameter	Simar and Wilson confidence intervals			
		99 per cent level		95 per cent level	
		lower	upper	lower	upper
Constant	37.64	21.57	70.73	25.51	68.93
Affiliation to *ITC* (1)	-20.97	-40.19	16.52	-39.41	5.20
Spatial location	-6.78	-13.05	-2.67	-13.61	-3.49
Firm's size	-10.26	-21.74	-4.35	-20.97	-6.00
Environmental study	-2.12	-5.63	8.11	-5.07	4.30
External management of wastes	-30.48	-58.73	-16.10	-57.45	-20.09
Sigma	1.242	0.199	1.748	0.365	1.698

(1) For variable affiliation to *ITC*, the Simar and Wilson confidence interval at 90 per cent level is [-38.48, -2.73].