SHADOW PRICES AND DISTANCE FUNCTIONS: AN ANALYSIS FOR FIRMS OF THE SPANISH PAVEMENTS INDUSTRY**

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SHADOW PRICES AND DISTANCE FUNCTIONS: AN ANALYSIS FOR FIRMS OF THE SPANISH CERAMIC PAVEMENTS INDUSTRY.

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ABSTRACT

This paper deals with the calculation of shadow prices for two industrial wastes generated on their production processes by a sample of eighteen firms belonging to the Spanish ceramic pavements industry. These prices are used to construct a corrected index of productivity which allows for considering wastes going with the production of marketable goods. It is followed the methodological approach first proposed by Färe, Grosskopf, Lovell y Yaisawarng (1993), which establishes a duality between distance and revenue functions. The shadow prices obtained for watery muds and used oils allow to measure in terms of a loss of marketable output the cost of achieving a marginal reduction in the production of these wastes. It is also found a negative correlation between absolute shadow prices and the intensity of wastes production, reflecting a greater marginal cost of eliminating wastes for those firms that have already made investments on cleaner procedures. Finally, differences between a conventional labour productivity index and a corrected productivity index are related to some firms' characteristics: size, recorded investments in cleaner technologies ad affiliation to a Ceramics Technological Institute, and found to be statistically significant.

Key words: shadow prices, duality, distance functions, revenue functions, ceramic pavements industry, environment, productivity.

JEL Classification: C61; D21; L68.

RESUMEN

En este trabajo se estiman los precios sombra de los residuos industriales que acompañan a la producción de pavimentos cerámicos de un conjunto de dieciocho empresas del sector. Estos precios son utilizados para construir una medida corregida de productividad que considera la producción de residuos como outputs no deseables. Para la obtención de los precios sombra se utiliza un enfoque basado en la dualidad entre función distancia y función de ingresos propuesto por Färe, Grosskopf, Lovell y Yaisawarng (1993). Los resultados muestran que los precios sombra de los lodos acuosos y aceites industriales usados representan un notable coste de oportunidad para las empresas, cuantificable en términos de pérdidas de producción deseable. Se observa, además, una cierta correlación negativa entre la intensidad de producción de residuos y el valor absoluto de sus precios sombra, lo que puede reflejar los mayores costes marginales de la reducción de residuos para aquellas empresas que ya vienen aplicando procesos de producción más eficientes en términos medioambientales. Finalmente, se comprueba que las diferencias entre el índice convencional de productividad del trabajo y el índice corregido están relacionadas en forma estadísticamente significativa con características de las empresas tales como su dimensión, la realización previa de inversiones en tecnologías limpias y la afiliación al Instituto Tecnológico de la Cerámica AICE.

Palabras clave: precios sombra, dualidad, función distancia, función de ingresos, industria de pavimentos cerámicos, medio ambiente, productividad.

1. INTRODUCTION

The consideration of the environment as a public good has unleashed a debate with regard to the convenience of breaking the tradition of assessing the value of industrial production by implicitly assuming that all goods produced are desirable from a social point of view. On the other side, when it is accepted that a part of industrial production is undesirable, and public authorities establish regulations to limit the emissions of polluting wastes, it is felt that the cost that firms have to incur in order to fulfil legal environmental restrictions, should be evaluated. In other words, it means that shadow prices for undesirable outputs have to be computed in order to measure in terms of opportunity costs the impact of environmental restrictions preventing free disposal of industrial wastes on firms performance.

Shadow prices of undesirable outputs could be understood in this context as the marginal cost that companies have to face in order to achieve a marginal reduction in the possibility of freely disposing of wastes generated in their production processes. From the point of view of public policies for environmental protection, the availability of these shadow prices would report several important benefits; among them, the possibility of comparing the marginal benefits of environment policies, with the cost they generate for private firms; the chance of checking if all firms face the same shadow prices; and, finally, the feasibility to adapt the traditional productivity indexes to allow for the consideration of different intensity of waste production among firms, sectors or even countries.

This paper deals with the calculation of shadow prices for undesirable outputs that are *byproducts* of the industrial production of ceramic pavements, with data coming from a sample of Spanish firms located at the industrial district of Castellon, on the Valencian region. We follow the distance function approach suggested by Färe, Grosskopf, Lovell and Yaisawarng (1993) (FGLY henceforth), that has also recently been applied by Coggins and Swinton (1996). This method uses output distance functions to derive shadow prices for all outputs (desirable and undesirable) generated by firms in their productive processes. In particular, it makes it feasible to obtain shadow prices for undesirable outputs without having to use exogenous information on wastes elimination costs coming from other studies, as is the case with the data set used by Pittman (1983) in a paper that addresses the task of adapting the multilateral productivity indexes pioneered by Caves, Christensen and Diewert (1982) for taking stock of polluting emissions that normally arise as a side effect of economic activities.

Secondly, this paper aims to propose a corrected measure of productivity that takes into account the residuals that emerge as a *byproduct* of current industrial production processes. Availability of residuals output data for each of the firms in our sample afford us to undertake this correction. This introduction is followed by a description of the methodology. Section three describes the sample and establishes the main results achieved, while section four concludes.

2. THE OUTPUT DISTANCE FUNCTION AND THE DERIVATION OF SHADOW PRICES

In order to illustrate the basic aspects of the methodological approach proposed by FGLY to derive shadow prices for outputs from distance functions, let's assume that we have a set of firms using a vector of inputs $x \in \Re_{+}^{N}$ to produce a vector of outputs $u \in \Re_{+}^{M}$, some of which can be considered as undesirable outputs. The *technology of reference* is represented by an output correspondence, which is a mapping $P: \Re_{+}^{N} \rightarrow P(x) \subseteq \Re_{+}^{M}$, where the output set *P(x)* represents the set of all feasible vectors of outputs given a vector of inputs *x*. It is also assumed that the *technology* satisfies the usual axioms initially proposed by Shephard (1970), which allows to define the *distance function in outputs* as the inverse of the maximum radial expansion of a given output vector, in such a way that the resulting output vector remains within *P(x)*, being attainable using the resources and the technology available. This *distance function* can be expressed as[1]:

$$D_o(x,u) = \inf\left\{\theta : (u/\theta) \in P(x)\right\}, \tag{1}$$

where $\theta \in\ ]0,1]$, given that $u \in P(x)$ if and only if $D_o(x,u) \leq 1$.

The assumptions made on the disposability properties of the technology are a key issue in order to derive output shadow prices. In particular it is assumed that firms can not freely eliminate (without any cost) the industrial wastes (undesirable outputs) that they generate in their production processes, either because it would require a greater use of inputs or because resources would have to be diverted from marketable

[1] This expression is equivalent to the reciprocal of the output oriented efficiency measure of Farrell (Farrell, 1957 and Färe y Lovell, 1978).

production in order to eliminate undesirable outputs. This condition can be incorporated to the characterisation of the technology by means of the axiom of weak disposal of outputs, in the sense that if $u \in P(x)$, it will also hold that $\theta u \in P(x)$, being in this case $0 \leq \theta \leq 1$.This assumption is consistent with the opportunity cost, measurable in terms of the loss of desirable production that firms would have to incur due to their compliance with environmental regulations, that impose a reduction of industrial wastes, and allows for undesirable outputs to have nonpositive shadow prices.

Next, we follow FGLY's approach to show that under certain assumptions, the shadow prices we are seeking can be obtained from the gradient vector of partial derivatives of an output distance function. This requires previously parameterise and estimate a distance function. The formal reasoning starts recognising the existence of a duality between the revenue function $R(x,r)$ and the output distance function $D_o(x,u)$. Denoting by r the output price vector , some of which components can be negative, the revenue function can expressed as:

$$R(x,r) = \sup_u \{ru : D_o(x,u) \leq 1\}, \tag{2}$$

while the *dual distance function in outputs* is given by:

$$D_o(x,u) = \sup_r \{ru : R(x,r) \leq 1\}, \tag{3}$$

being ru the inner product of the output prices and quantity vectors.

Then, assuming that the revenue and distance functions are both differentiable, a *Lagrange* problem can be set up to maximise revenue, and first order conditions yield the relationship (Färe and Primont, 1995):

$$r = R(x,r)\nabla_u D_o(x,u) \tag{4}$$

where ∇ is the gradient operator.

Expression (3) can be developed as a relationship between the distance function and the shadow prices, so that:

$$D_o(x,u) = r^*(x,u)u\,, \tag{5}$$

where $r^*(x,u)$ represents the output price vector that maximises revenue. Applying *Shephard's dual lemma* to expression (5), yields:

$$\nabla_u D_o(x,u) = r^*(x,u), \tag{6}$$

expression that combined with (4), leads to:

$$r = R(x,r)\, r^*(x,u) \tag{7}$$

In expression (7), $r^*(x,u)$ are obtained from the gradient of the distance function, and represents revenue-deflated output prices. The main difficulty that arises in order to obtain absolute shadow prices from expression (7) relies on the dependence of the revenue function *R(x,r)* on *r*, that is precisely the vector of shadow prices we are seeking. The alternatives to deal with this problem are basically two. First, it can be assumed that the observed price of an output *m*, r_m^o, equals its absolute shadow price, represented by r_m, which allows to obtain the maximum revenue as:

$$R(x, r_m^o) = r_m^o / r_m^*(x,u), \tag{8}$$

expression that can be used to calculate the absolute shadow prices of the remaining outputs from its deflated shadow prices r^*. Denoting by $r_{m'}$ the absolute shadow prices for outputs other than *m*, we get:

$$r_{m'} = R\, r_{m'}^*(x,u) = R\,\frac{\partial D_o(x,u)}{\partial u_{m'}} = r_m^o\,\frac{\partial D_o(x,u)/\partial u_{m'}}{\partial D_o(x,u)/\partial u_m} \tag{9}$$

On the other hand, an alternative way to handle the problem above is to suppose that a zero-profit and revenue-maximising firm would incur in an observed cost equivalent to its observed revenue *R(x,r)* (Färe and Primont, 1995), and simply use expression (7) to obtain absolute shadow prices.

The last step is to parameterise and estimate the distance function to proceed with the calculation of the absolute shadow prices along the lines we have showed before.

After absolute shadow prices have been computed, we proceed to use them with the aim of formulating a *corrected productivity index* allowing for the consideration of different intensity of waste production among firms. Let's make a partition of the quantity and output price vectors, so that $u = (u_a, u_b)$ and $r = (r_a, r_b)$, where $u_a = (u_1, \ldots, u_J)$ and $u_b = (u_{J+1}, \ldots, u_M)$ are the quantity vectors of desirable and undesirable outputs, respectively, while $r_a = (r_1, \ldots, r_J)$ and $r_b = (r_{J+1}, \ldots, r_M)$ are the price vectors also for good and bad outputs.

Considering only desirable outputs, the *partial productivity index for input* x_j, can be expressed as:

$$PI = \frac{r_a u_a}{x_j} \tag{10}$$

However, estimation of shadow prices for undesirable outputs, allows to define a *corrected index of partial productivity for input* x_j, as in the following expression:

$$CPI = \frac{(r_a u_a) + (r_b u_b)}{x_j} = \frac{ru}{x_j} \tag{11}$$

Given that shadow prices for bad outputs are nonpositive, the corrected productivity index will always take values equal or smaller than the traditional productivity index of expression (10); this allows for defining an *index of productivity bias* as:

$$PBI = \frac{PI}{CPI} = \frac{r_a u_a}{ru} \tag{12}$$

Expression (12) will be equal or greater than one and will serve as a measure of the degree of overvaluation in quantifying *input* x_j productivity levels when only marketable output (*good output*) is being considered with disregard of those wastes that arises as a *byproduct* and have potential harmful effects on the environment.

3. DATA AND EMPIRICAL FINDINGS

The sample used in this paper comes from a cross-section data set of eighteen Spanish *ceramic pavements* producers located at the *industrial district* of Castellon, on the Mediterranean coast. The source of the data is the *Valencian Community Inventory of Industrial Residuals* elaborated in 1995 by the *Department of Environment* of the *Valencian Regional Government*. All firms face the same productive process, which is characterised by the production of one desirable output, *ceramic pavements* (u_1), and two wastes or undesirable outputs, *watery muds* (u_2) and *used oil* (u_3). Inputs are *clay, kaolin, felspar and limestones* (x_1), as intermediate input, and *labour* (x_2) and *capital* (x_3), as primary inputs. Labour input is measured in terms of the number of workers, while capital is proxied by energy consumption in kilowatts/hour. *Table 1* presents some descriptive statistics of the data.

Table 1: Sample description

Variable	*Description*	*Units*	*Mean*	*Standard deviation*	*Maximum*	*Minimum*
u_1	Ceramic pavements	Square meters	*2.031.077*	*1.168.311*	*4.500.000*	*200.000*
u_2	Watery muds	Tons	*2.908*	*4.108*	*15.648*	*14*
u_3	Used oil	Kilograms	*1.822*	*3.135*	*12.000*	*100*
x_1	Clay, kaolin, felspar and limestones	Tons	*50.192*	*40.762*	*144.000*	*3.300*
x_2	Labour	Number of workers	*128*	*121*	*428*	*25*
x_3	Capital	Kilowatts/hour	*4.573*	*4.705*	*20.000*	*500*
$r_{u_1}^0$	Observed price	Euros/square meter	*6,76*	*3,74*	*15,91*	*2,80*

Following *FGLY*, the *distance function in output* is parameterised as a *translog* function, which is given by the following expression:

$$\ln D_o(x,u) = \phi + \sum_{n=1}^{3} \beta_n \ln x_n + \sum_{m=1}^{3} \alpha_m \ln u_m + \tfrac{1}{2}\sum_{n=1}^{3}\sum_{n'=1}^{3} \beta_{nn'} (\ln x_n)(\ln x_{n'}) + \tfrac{1}{2}\sum_{m=1}^{3}\sum_{m'=1}^{3} \alpha_{mm'} (\ln u_m)(\ln u_{m'}) + \sum_{n=1}^{3}\sum_{m=1}^{3} \gamma_{nm} (\ln x_n)(\ln u_m) \tag{13}$$

where *m* and *n* denote outputs and inputs, respectively.

The *translog* function is a flexible functional form that does not impose strong disposability of outputs and allows for strong substitutability of inputs; however, given the large number of parameters in relation to the size of our sample it is not possible to use econometric methods. Alternatively, the parameters in expression (13) can be obtained using mathematical programming techniques[2] (Aigner and Chu, 1968), by solving the following optimisation program:

$$Max \sum_{k=1}^{18} \left[\ln D_o\left(x^k, u^k\right) - \ln 1 \right] \tag{14}$$

$s.t.$

$$\ln D_o\left(x^k, u^k\right) \leq 0 \qquad k = 1,\ldots,18. \qquad (i)$$

$$\frac{\partial \ln D_o\left(x^k, u^k\right)}{\partial \ln u_m^k} \geq 0 \quad m = 1; \quad k = 1,\ldots,18. \qquad (ii)$$

$$\frac{\partial \ln D_o\left(x^k, u^k\right)}{\partial \ln u_m^k} \leq 0 \quad m = 2,3; \quad k = 1,\ldots,18. \qquad (iii)$$

$$\left\{ \begin{array}{l} \sum_{m=1}^{3} \alpha_m = 1 \\ \sum_{m'=1}^{3} \alpha_{mm'} = 0 \\ \sum_{m=1}^{3} \gamma_{nm} = 0 \end{array} \right\} \qquad m = 1,2,3; \quad m' = 1,2,3; \quad n = 1,2,3. \qquad (iv)$$

$$\alpha_{mm'} = \alpha_{m'm} \qquad m = 1,2,3; \quad m' = 1,2,3. \qquad (v)$$

$$\beta_{nn'} = \beta_{n'n} \qquad n = 1,2,3; \quad n' = 1,2,3. \qquad (v')$$

where *k* denotes firms.

The set of restrictions in (i) imply that each observation is located either on or below the technological frontier; the restrictions contained in (ii) guarantee that desirable output will have nonnegative shadow price for all firms, while (iii) assures that undesirable outputs will have nonpositive shadow prices, also for all firms. The assumption of weak disposal of outputs is introduced by restriction (iv) that imposes homogeneity of degree +1 in outputs; finally (v) and (v') impose symmetry.

The objective function in (14) minimises the sum of the deviations of individual observations from the frontier. However, we are in fact maximising because the distance function takes positive values lower or equal than one, and therefore its log can take negative or zero values; in consequence, to maximise the deviations of the

[2] Comparing to econometric approaches, mathematical methods yield parameters without statistical properties, which prevents further inference studies. Moreover, it is also well known that the outcomes obtained through mathematical programming techniques can be strongly affected by the presence of outliers in the sample.

distances expressed in logs from zero (represented by the log of one) is equivalent to minimise the sum of the absolute deviations of the individual observations.

Table 2 shows the parameter estimates of the *translog* function given by expression (13). Using those figures and the available information, the value of the individual firm output distance function has been computed, and the sample average is 0,927. It is well known that the output distance function is the reciprocal of Farrell´s measure of output efficiency whose average value is 1,079. This means that taking into account the technical relation existent among inputs, marketable output, and undesirable outputs in the firms of the sample, as a rule of thumb, by making an efficient use of their available resources, these firms would be able to increase their production of ceramic pavements almost by an eight percent[3].

Table 2: Estimated parameters of the translog distance function. Expression (13)

Parameter		*Parameter*	
ϕ	*47,253*	α_{12}	*-0,014*
β_1	*-13,459*	α_{13}	*-0,025*
β_2	*-0,403*	α_{22}	*0,001*
β_3	*1,459*	α_{23}	*0,013*
α_1	*3,112*	α_{33}	*0,012*
α_2	*-2,322*	γ_{11}	*-0,131*
α_3	*0,210*	γ_{12}	*0,098*
β_{11}	*1,519*	γ_{13}	*0,033*
β_{12}	*0,250*	γ_{21}	*-0,079*
β_{13}	*-0,898*	γ_{22}	*0,134*
β_{22}	*0,080*	γ_{23}	*-0,055*
β_{23}	*-0,401*	γ_{31}	*-0,018*
β_{33}	*2,327*	γ_{32}	*0,013*
α_{11}	*0,039*	γ_{33}	*0,005*

The estimation of the distance function allows us to obtain output shadow prices for each firm in our sample, as we explained above. In order to get the *shadow income* of each productive unit, we use expression (13) under the hypothesis that the shadow

[3] In order to make a right interpretation of this outcome, it should be considered that mathematical methods give place to a number of efficient firms that goes up as the number of restrictions imposed on the optimisation programs increases. In our case, the high average efficiency level is affected by the high number of restrictions in (14).

price of good output (ceramic pavements) is equal to its observed market price; this is equivalent to assume that $r_m^o = r_{u_1}^o$, being $r_{u_1}^o$ the square meter of pavement market price, a figure which is different for each company. *Table 3* shows the computations for output shadow prices; simple means and standard deviations, as well as weighted means[4] are reported.

Table 3: Output shadow prices (*)

	$r_{u_1}^o$	r_{u_2}	r_{u_3}
Mean	*6,76*	*-9.830,6*	*-1.043,7*
Standard Deviation	*3,74*	*23.345,9*	*2.512,8*
Weighted Mean	*6,84*	*-336,6*	*-125,5*
Maximum	*15,91*	*-79.893,5*	*-9.998,6*
Minimum	*2,81*	*0,0*	*0,0*

(*) Euros.

The shadow prices of the industrial wastes could be interpreted as the marginal loss of revenue that would represent for a firm the volume of resources needed to reduce its emission in a marginal unit. Therefore, in average terms, the reduction in a ton of the production of *watery mud*, residual u_2, means that a firm should make use of resources valued in 336,6 euros, which in terms of marketable output would imply an implicit loss of 49,2 square meters of pavements, considering that the market price for square meter is 6,84 euros on average. Similarly, and in order to reduce the production of *used oil* in a kilogram, residual u_3, the opportunity cost would be valued in 125,5 euros, which again in terms of good output, would suppose a reduction in production of 18,3 square meters.

Shadow price estimates differ significantly among firms, as the high standard deviation of those prices reveals; this result is consistent with FGLY, and it is also related to important differences among firms in terms of quantities of residuals discharged per unit of desirable output produced. After shadow prices at firm level have been obtained, correlation between absolute values of these prices and waste emission for square meter of ceramic pavements has been computed, getting a negative correlation close to 30 percent in the case of *watery mud* and around 25 percent for

[4] Weighted means of shadow prices for bad outputs have to be interpreted as the cost of reducing in an unit its production within the whole sample.

used oil. The correlation coefficient has the expected sign if it is kept in mind that companies that produce a greater volume of residuals per unit of marketable production are very likely to be those that rely on technical equipment less adapted to recycling those residuals or minimising their delivery, and for them investments intended to cut the volume of effluents would have a relatively small cost in comparison with their prospective yields in terms of reduction of emissions. On the opposite side, those firms that have already reached a high performance according to their ability to control the environmental impact of their production processes would face a higher marginal cost in case of stepping-up their efforts to reduce waste discharges. This would be reflected in a higher shadow price for *bads* in these companies.

These results could be of interest in designing an efficient regulation of some aspects related to the industrial contamination issue. The shadow prices that have been estimated reflect a wide variety of firms positions as for the marginal cost of reducing the emission of residuals in the Spanish ceramic industry. On the other hand, the pattern of close knitted geographical localisation of these firms makes it reasonable to assume that marginal social benefits of cutting current levels of industrial contamination are probably similar among companies, because they share a common natural landscape, and the same natural resources and human habitat. If an efficient regulation means that the marginal cost of decreasing current contamination levels has to be made equal to the marginal social benefits, it makes sense to deduce that the current situation is not efficient in terms of the allocation of resources. It is difficult to deepen from these basic statements without being able to incorporate more detailed data on firms technology and their output mix, but it seems fine to infer that some conditions exist so that a market of emission permits could be developed where some firms would wish to enter as buyers and others as suppliers. In order to fulfil environmental regulations, each firm would have to choice carrying out fresh investments or acquiring emission permits.

Finally, it is good to remark that the knowledge on shadow prices allows the researcher to approach a valuation of industrial production not confined to marketable production and market prices, but able to include an estimate of the (negative) value of a likely increase in industrial refuses, linked to the expansion of *good* output levels. The type of shadow prices computed in this paper are derived strictly from technical relations between inputs and outputs and should be considered as estimates arising from a *producer approach*. Externalities on consumers or other producers are not taken into account, but could be incorporated in a straightforward way, provided adequate data are made available, within the same framework of analysis, as shown in Färe and Grosskopf (1998). Despite their shortcomings, the shadow prices we have used illustrate well enough the effects on production valuation of including in the price vector several components with a negative sign, each corresponding to a different undesirable output.

We now proceed to compute two different measures of labour productivity, one along the conventional lines, as a quotient between the monetary value of each firm marketable output (ceramics pavements) and labour staff, and a *corrected* one, defined by expression (20). The outcome of using both types of productivity indexes appear in *Table 4*. Both productivity measures differ by values that go from 3 per cent to 30 per cent in the sample, with an average *gap* close to 12 per cent. It means that differences are important enough to make an impact on firms comparisons. As an example, firm number eight is more productive in conventional terms than firm number five, but it changes when an environmental-friendly approach is taken and waste production from both firms are included in the numerator of the productivity quotient, using shadow prices to translate residuals quantities to monetary figures. Now firm five is more *productive* than firm eight. Ranking between firm four and firm ten is also inverted when moving from a productivity measure to the other, and two firms (numbers eleven and thirteen), that have quite similar labour productivity levels when only good output is compared, show marked differences when *bads* are also contemplated.

From society's comprehensive view it is clearly a serious matter of concern. It is not possible to remain aloof to the fact that a given productivity level can be achieved with very different volumes of real or potential noxious wastes, and a virtue of the very simple indicator we propose is to ease the transition to a new way of analysing entrepreneurial performance, apt enough to accueil a growing public interest in environmental values. Firms that have undertook costly investments in new equipment that allows cleaner production processes should have their efforts (that consume productive resources), recognised and not merely dismissed as *less productive* in conventional terms.

Next step is to disclose if a relationship exists between our *bias productivity index* and some firm's characteristics, making use of variance analysis. We have broken our sample in two groups, one of them, *group A*, includes those firms with a lower than average bias, and *group B* comprises all those firms with higher than average bias. Then we have tried to ascertain if there is a statistically significant difference between both subsamples concerning to five distinct variables: *size, affiliation to a Technological Institute*[5]*, spatial location*[6]*, a record of past investments in cleaner technologies,* and *use of external services for waste management.*

Table 4: Labour productivity measures (*)

Firm	*Labour productivity*	*Corrected labour productivity*	*Productivity Bias Index*
1	*57,81*	*44,33*	*1,304*
2	*202,81*	*179,74*	*1,128*
3	*120,65*	*109,12*	*1,106*
4	*79,30*	*65,71*	*1,207*
5	*96,66*	*91,72*	*1,054*
6	*91,07*	*80,38*	*1,133*
7	*64,96*	*62,49*	*1,040*
8	*97,02*	*84,59*	*1,147*
9	*127,83*	*124,01*	*1,031*
10	*77,38*	*73,64*	*1,051*
11	*127,91*	*114,24*	*1,120*
12	*194,59*	*167,23*	*1,164*
13	*127,83*	*118,42*	*1,079*
14	*121,29*	*105,28*	*1,152*
15	*115,48*	*94,10*	*1,227*
16	*105,18*	*92,58*	*1,136*
17	*126,67*	*108,74*	*1,165*
18	*166,61*	*159,20*	*1,047*
Mean	*116,73*	*104,20*	*1,127*
Standard deviation	*39,97*	*36,41*	*0,072*

(*) Euros per worker.

[5] The Region of Valencia possesses a network of Technological Institutes specialized by branches of industrial production, AICE being the one concerned with the ceramics industry. They are non-profit entities under the form of business associations sponsored and mostly funded by the public authorities and oriented to promote technological innovation, best practice diffusion and quality tests. They provide external services (R&D etc.) at low cost to their affiliates, that are mostly small and medium sized firms. Affiliation is normally considered as an index of innovative behaviour on the part of firm's management.

[6] The ceramics pavements industry is highly concentrated in a small number of contiguous municipalities in the Castellón Province, where firms are supposed to enjoy important external economies that could be broadly defining a marshallian type industrial district in the sense coined by the economics geography literature. We hypothesize that close proximity improves the chances of firms being more sensible to good practice in terms of waste management, trough imitation and easier technical information diffusion.

Results are shown in *Table 5* and are clearly conclusive for all the variables under consideration. Firms of greater size show a smaller bias and the same happens for firms that have recorded investments conducive to cleaner production processes. External management of wastes is mainly associated to the firms with higher bias. It was to be expected given that those firms are more intensive in terms of production of industrial wastes, that forces them into a greater dependence of external suppliers of services (transport, storage, among others) for waste disposal. Affiliation to a *Technological Institute* specialised in the ceramics industry (*AICE*), helps to reduce the bias, as variance analysis shows. This finding is probably linked to the services provided by the *Institute* in terms of technological consultory, easing the access to *R&D* in different fields, including the development and application of waste reducing techniques, and favouring diffusion of industry's best practice. The variable *spatial location* is employed to distinguish the firms that are located in one area of very dense concentration of this type of industry (the *Plana Baixa* zone) and the others. We presume that the first enjoy an advantage in terms of sharing the external economies generated by a dynamic industrial district, that gives them rapid access to information released by suppliers of new industrial equipment and competitors and that facilitates the acquisition of better practices in dealing with industrial residuals. Evidence, after performing variance analysis, conforms to it.

Table 5: Variance analysis

	Firm's size (3)	*Affiliation to Technological Institute*	*Spatial Location*	*Investments on cleaner technologies*	*External management of waste u_2*
mean group A (1)	*2.966,2*	*0,63*	*0,75*	*1,00*	*0,13*
mean group B (2)	*1.283,0*	*0,10*	*0,30*	*0,60*	*0,90*
Statistic F	*18,983*	*7,063*	*4,000*	*4,740*	*24,063*
p-value	*0,000*	*0,017*	*0,063*	*0,045*	*0,000*

(1) Bias smaller than average bias for the whole sample; 8 firms.
(2) Bias greater or equal average bias for the whole sample; 10 firms.
(3) Thousand of squared meters of ceramic pavements.

4. CONCLUDING REMARKS

This paper has been devoted to estimate shadow prices for two different types of undesirable outputs or industrial wastes generated in their production processes by eighteen Spanish firms in the ceramic pavements industry. The methodology follows the approach suggested by Färe, Grosskopf, Lovell and Yaisawarng (1993). Accordingly, central importance has been given to the duality between output distance and revenue functions, using the former to derive output shadow prices.

The shadow prices obtained for *watery muds* and *used oil* (industrial wastes that are *by-products* in the production of marketable ceramic pavements) have made it feasible to measure in terms of loss of marketable output production (square meters of ceramic pavements) or its equivalent in cash revenue, the opportunity costs firms would have to incur in order to achieve a marginal decrease in the production of those refuses. A negative correlation has been observed between the intensity of waste production by firms (as a proportion of their own production of ceramic pavements) and absolute shadow prices computed for these undesirable outputs. This feature probably reflects a greater marginal cost of polluting residues elimination for those firms that had previously invested on cleaner technologies directed to get rid of undesirable outputs, and are currently generating less units of wastes for square meter of ceramic pavements produced.

Another empirical result of some importance is the observation of a high dispersion of shadow prices among firms. This should be a matter of concern for policy makers aiming to establish an efficient environmental regulation on the Spanish ceramics pavement firms located at the *industrial district* of Castellon (a densely populated area), since for a similar marginal social benefit to be obtained from a cut in current pollution levels across sample firms, the marginal costs that those firms would have to face would be quite different.

Finally we wished to use shadow prices to put stress on the need to improve current productivity indexes to take industrial waste into consideration. Our results show that clear differences arise within the sample when computing conventional and corrected measures of labour productivity at firm level. Those differences are associated in statistically significant terms to some variables corresponding to firms characteristics, like *size*, record of former *investments in cleaner technologies*, and affiliation to a *Technological Institute for the Ceramics Industry.*

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