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Eco-Efficiency: Environmental Performance vs Economic Performance

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The second half of the 20th century was characterized by an increasing interest in the pace of economic growth and its impact on the environment. As a result, the concept of eco-efficiency as a philosophy of management has arisen, which combines the excellence of the environment and business. This paper uses the distribution-free approach to provide empirical evidence in relation to the eco-efficiency paradigm by studying the relation between environmental performance (measured by the level of emissions of air-contaminating substances) and economic performance (approximated by economic efficiency), in 199 companies from mineral manufacturing industry in Spain between 2004 and 2007. The empirical analysis shows that the results are consistent with the paradigm of eco-efficiency and therefore it can be concluded that being responsible for the environment is positively related to economic efficiency.

Keywords: eco-efficiency, economic efficiency, environmental performance, distribution-free approach

Introduction

The paradigm of eco-efficiency confirms the possibility of achieving better environmental performance without reducing economic results (Schaltegger & Sturm, 1999). According to Huppes and Ishikawa (2005), satisfying the increase in consumption of the world's population and obtaining a reasonable environmental quality explain why eco-efficiency is necessary, and its practical and theoretical importance stems from its ability to combine performance throughout two out of three areas of sustainable development, environment and economics (Ehrenfeld, 2005). In this sense, and in the highly competitive conditions that exist nowadays, it is essential for companies to internalize a challenge that involves environmental matters. Eco-efficiency may be the answer to that challenge, as it refers to the process that aims to minimize the environmental impact of business activity on the surrounding conditions and, at the same time, to increase the effectiveness and efficiency of production processes by respecting the environment and creating business value.

In order to achieve this objective, eco-efficiency attempts to establish bases which enable effective management of a product's life cycle by attempting to improve the use of the inputs in production and reducing waste materials and contamination (Schmidheiny, 1992), combining in that way the excellence of the

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environment and business (DeSimone & Popoff, 1997), in other words, increasing productivity while decreasing the environmental impact of the company (Bebbington, 2001; Lehman, 2002; Stone, 1995).

Traditionally, the connection between competitiveness and the environment has made people think wrongly that the latter involves higher costs, which reduce competitiveness due to the prevention of pollution and waste treatment. Nevertheless, this point of view ignores important benefits that enable a company to introduce practices that respect the environment and may activate innovations which reduce the cost of a product or increase its value (Porter & van der Linde, 1995), which eventually results in increased levels of economic efficiency. Those innovations can reduce costs in two ways: firstly, by reducing the number of resources used, and secondly, by modifying the choice of applied resources. The combination of those two types of efficiencies constitutes the efficiency of costs. Moreover, the innovations may also increase the value of a product which would allow a company to set a higher price for a product and, as a result, improve the levels of income efficiency.

Many previous studies have evaluated eco-efficiency through different methodological variants (De Koeijer, Wossink, Struik, & Renkema, 2002; Korhonen & Luptacik, 2004; Kuosmanen & Kortelainen, 2005; Zhang, Bi, Fan, Yuan, & Ge, 2008; Picazo-Tadeo, Gómez-Limón, & Reig-Martinez, 2011; Gómez-Limón, Picazo-Tadeo, & Reig-Martinez, 2012; Picazo-Tadeo, et al., 2012; Sarkis & Cordeiro, 2012). Numerous works can also be found in the literature that deal with the relationship between economic performance and environmental performance (Shrivastava, 1995; Russo & Fouts, 1997; Konar & Cohen, 2001; Murty & Kumar, 2003; Al-Tuwaijri, Christensen, & Hughes, 2004; Elsayed & Paton, 2005; Burnett & Hansen, 2008), as well as studies which show that contamination stems from bad financial results (Hamilton, 1995; Hart & Ahuja, 1996)[1]. What is more, some of the authors state apart from precaution, eco-efficiency also aims for environmental regeneration (Huppes & Ishikawa, 2005; Myer, 1992; Mohr, 2002; Xepapadeas & Zeeuw, 1999; Epstein & Roy, 1997; Dowell, Hart, & Yeung, 2000; Blumberg, Korrsvold, & Blum, 1997; Peck & Sinding, 2003).

All the above-mentioned authors agree that it is compatible to be responsible with the environment as well as generate business value, and therefore investment in eco-efficiency should be perceived as an opportunity to achieve competitive advantages for the company (Porter & van der Linde, 1995; Picazo-Tadeo & Prior, 2009). However, the great majority of companies still do not apply the concept of eco-efficiency in their strategies, mainly for two reasons. Firstly, investing in eco-efficient strategies[2] is in many cases expensive and normally the effects are obtained over the long term. Secondly, there is widespread belief that environmental norms undermine competitiveness (Porter & van der Linde, 1995), since they are perceived more as an impediment than an opportunity to achieve competitive advantages.

Usually, studies on eco-efficiency bring cost-efficient economic performance closer by analysing the effects of environmentally responsible behaviour on companies' costs (Burnett & Hansen, 2008). On the other hand, the studies do not include the effects of environmentally responsible behaviour on companies' incomes. However, due to the growing social interest in environmental matters, those companies that apply eco-efficient strategies may not only reduce their costs but also have bigger demand for their products and/or set surcharges,[3] which results in higher incomes for those companies.

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[1] A more detailed review of the literature on the subject is gathered by Molina-Azorín et al. (2009).

[2] The concept of eco-efficient strategies in this paper refers to the business strategies which were carried out in order to reduce the impacts on the environment and at the same time to generate business value (Sinkin et al., 2008).

[3] Emission of the material's particles into the air.

This paper studies the connection between environmental performance and economic performance by considering the effects of environmentally responsible behaviour on both companies' costs (cost-efficiency) and incomes (efficiency benefits), providing in this way empirical evidence for the paradigm of eco-efficiency. Thus, environmental performance is approximated for a weighted average of the values of five important pollutants (CO, CO_2, NO_2, SO_2, and PM), and economic performance is approximated for economic efficiency. Unlike Burnett and Hansen (2008), who use SO_2 for approximation of environmental performance, in this paper we will use five pollutants to set the contamination profile for each firm. However, according to Ilinitch, Soderstrom, & Thomas (1998), the task to define environmental outcome is not so easy and any index of performance, or even a category of it, which can be defined, is probably not enough to evaluate it accurately. In this sense manifests Lanen (1999), suggesting that in a study of cases of environmental performance and waste management, one way to see the relevance of any environmental performance is to assess how it is affected by a change in the measure (estimate) of pollution. According to the author, the proposed measure in this paper is appropriate for evaluating the environmental performance of companies producing miners. The remaining structure of this paper is as follows. First, there is a brief review of the literature and hypotheses are proposed. Section three discusses the research model and section four presents the empirical results. Finally, present and discuss the conclusions.

Theoretical Development and Hypotheses

The concept of eco-efficiency was raised during the second half of the 20th century in response to growing interest in the effect of economic growth on the environment, and the development of initiatives such as the "Club of Rome"[4], reports and scientific papers like "The Limits to Growth" (Behrens, D. H. Meadows, D. L. Meadows, & Randers, 1972), Informe Founex (1971), I = PAT[5] (Ehrlich & Holdren, 1971) and the Stockholm Declaration (1972), among others. The latter establishes the concept of eco-development or eco-socioeconomy as a development option that combines economic growth, an increase in egalitarian social welfare and environmental preservation. In the following years, a series of conferences from international organizations interested in the subject re-held such as the meeting of the World Commission on Environment and Development. The Commission published a report called "Our Common Future" (1987), which defined in a more operational way the proposed development as sustainable development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

The concept of sustainable development had its culmination in the great worldwide event held in Rio de Janeiro,[6] where the term "eco-efficiency", introduced previously by Schaltegger and Sturm (1990), became widespread in the business world, mainly due to the paper of Schmidheiny (1992). This paper considers the importance and need for the adoption of eco-efficient strategies by managers in order to make production

[4] In 1968, a group of 105 scientists and politicians met in Rome, who came from 30 different countries to discuss the changes that were taking place on the planet as a result of human actions. Two years later, the Club of Rome would be created and legalized under Swiss law. Thirty years later, it would have among its partners more than 100 specialists from over 52 countries, publishing over 21 reports of great environmental interest and maintaining a strong position in these issues of the environmental sphere, internationally recognized.

[5] The human impact on the environment was calculated by the population (P), consumption per capita and technology (A) and the environmental impact per unit consumed (T).

[6] The UN Conference on Environment and Development, also known as the Earth Summit, comprised a number of international summits held in Rio de Janeiro (Brazil) from June 3 to June 14 1992 and in Johannesburg (South Africa) from 26 August to 4 September 2002. Lectures were unprecedented in the sphere of the United Nations, both in size and in the scope of their motives. At the Earth Summit of Rio, 172 governments participated, including 108 heads of state or government.

processes more efficient in the use of resources and waste management, thereby cooperating with conservation of the environment and simultaneously creating a firm value. Thus, eco-efficiency became to be considered as the business response to the challenges posed by sustainable development (Ehrenfeld, 2005). According to DeSimone and Popoff (1997), sustainable development is the best solution to the challenge of sustainability, provided that this development takes into account seven guidelines for eco-efficiency: (1) reduce the intensity of use of raw materials in the production of goods or services; (2) reduce the intensity of use of energy consumed in obtaining goods or services; (3) reduce toxic dispersion; (4) increase recycling of materials; (5) maximize the use of renewable resources; (6) extend product durability; (7) increase the intensity of product services, that is, create additional value for consumers, for example, through providing multifunctional products and sharing.

According to the above, the interconnection between sustainable development and eco-efficiency is obvious, because to achieve the first, the latter should be implemented in production processes. As Sachs (2009, p. 20) suggests that "must rethink the climate threat as an opportunity for transformation and global cooperation in a number of technological advances in order to achieve sustainable development". However, eco-efficiency does not guarantee sustainability, as this depends basically on restructuring society in social apart from the environmental and economic issues (Hoffrén & Apajalahti, 2009). Therefore, eco-efficiency has been classified as emerging "socioeconomic theory" (Birkin & Woodward, 1997a, 1997b), as "a management philosophy", or as "an administrative control process" (DeSimone & Popoff, 1997), depending on the status of the scientific author concerned.

Closely related to the concept of eco-efficiency is eco-innovation, which is the result of effective implementation of eco-efficient strategies. Thanks to eco-innovation, companies guarantee that the competitive advantage obtained by environmental improvement is sustained. However, innovation requires a change in the patterns of pre-established action, which can be initially stimulated with the support of public policies, for example, through environmental regulations to induce eco-efficiency. This type of eco-efficiency is called "guided eco-efficiency". Other companies which are more aware adopt a proactive attitude related to the environment, i.e., integrate, by free choice of their managers, eco-efficient strategies. That eco-efficiency is called "voluntary eco-efficiency", and according to Al-Tuwaijri et al. (2004), a company that applies this concept will get better results than those that apply guided eco-efficiency. Following the approach given by Reinhardt (1999), environmental regulations applied to a sector cause the effect known as "free lunch", i.e., companies can take benefit from savings in production costs, but this does not necessarily mean an improvement in their competitive position, since all companies in this sector have the same opportunities to improve. In that case, it only benefits the company that goes beyond compliance with the law, i.e., the one with a proactive environmental management policy.

In short, the growing societal concern for environmental issues is directly affecting business decisions. In this sense, companies that apply eco-efficiency strategies can not only reduce costs but may also be more valued in the market than similar companies which have not adopted these strategies (Sinkin, Wright, & Burnett, 2008). Consequently, it can say that customers reward environmentally responsible companies by demanding more products and/or paying extra for them, which means a major source of revenue for those with a differential ecological (opportunity), while governments penalize organizations that inflict laws protecting the environment (threat). Nevertheless, many companies are still reluctant in these issues, as they often do not consider that compliance with environmental regulations can stimulate innovation, with the consistent reduction of costs through greater investment in research and the use of clean technologies (Porter, 1991; Porter

& van der Linde, 1995; Hart, 1995; Shrivastava, 1995; Karagozoglu & Lindell, 2000; Mohr, 2002), as well as avoiding future costs arising from government sanctions (DeSimone & Popoff, 1997; Ekins, 2005). Thus, public policy intervention can promote innovation, resource productivity and competitiveness through the development of properly designed legal laws. So, being responsible with the environment leads to adopting eco-efficient strategies that could contribute to improving a company's competitive position; therefore, in line with Porter and van der Linde (1995) when they say that "contamination equals inefficiency", defines the following working hypothesis:

H_0: Being responsible for the environment is positively related to economic efficiency.

As noted above, it is traditionally considered that environmentally friendly production may increase production costs since pollution is a negative output and to decrease a negative output requires additional inputs, and therefore increased costs. However, numerous researchers have argued that pollution is a form of inefficiency and reducing it leads to an increase in production efficiency and therefore a reduction in costs (King & Lenox, 2002; Porter, 1991; Porter & van der Linde, 1995).

By adopting eco-efficient strategies, companies can not only save costs by using more and better resources, but also reduce the negative impact on the environment. This allows us to formulate the following sub-hypothesis:

H_1: Being responsible for the environment reduces a company's costs.

Also, being respectful to the environment not only reduces costs, but can also have positive effects on revenue and generate greater profit for the company. An increasing number of customers are aware of the environment, and a conscientious consumer is more likely to pay a higher and/or demand products and services produced in a way that respects the environment (Nidumolu, Prahalad, & Rangaswami, 2009; Thomas, et al., 2007). Furthermore, companies may also be differentiated more easily in the market if they offer products or services that respect the environment (Unruh & Ettenson, 2010). Therefore we propose the following sub-hypothesis:

H_2: Being responsible for the environment increases the profit of the company.

The Model

A fundamental question when measuring economic efficiency is to decide which will be the concept to use. In this sense, it is considered that the two most important concepts of economic efficiency are cost-efficiency and profit efficiency, since they are based on economical optimization in reaction to prices and competition in the markets and not on the use of a particular technology; in other words, these two concepts of efficiency in turn respond to two important economic objectives: cost minimization and profit maximization (Berger & Mester, 1997).

The idea that a company maximizes its performance by adopting behavior that respects the environment supports the apparent increase in costs due to the adoption of measures to reduce environmental pollution, because, as Berger and Mester (1997) argued, profit efficiency is not necessarily positively correlated with cost-efficiency, which implies that eventual major costs as a consequence of reducing pollution could be compensated by major revenue when other product portfolios are used or take advantage of the power in the market prices due to its specialization (Maudos, Pastor, Pérez, & Quesada, 2002). This idea involves the possibility that the occurrence of higher production costs due to the introduction of environmental improvements in the company would not necessarily mean a decrease in its performance.

The costs of inefficiencies are due to management errors and/or organization mistakes and could be defined as the difference between a company that could potentially use its resources and its current use; it also says how much higher the costs are of an inefficient firm in relation to the cost of a more efficient company that produces the same combination of outputs and prices of inputs and the difference cannot be explained by random error.

Cost-efficiency is derived from a cost function that relates the observed costs of a set of outputs, prices of inputs, one random error and inefficiency. This function can be written as:

$$C = C(y, w, u_c, v_c) \tag{1}$$

where C measures the variable cost, y is a vector of quantities of outputs, w is the vector of input prices, u_c represents the inefficiency found, and v_c represents the random error. The inefficiency term u_c incorporates both allocative inefficiency, resulting from a non-optimal reaction to relative input prices w, and technical inefficiency, due to using too many inputs to produce y. To facilitate the estimation of inefficiency it is assumed that the random error and inefficiency v_c and u_c are separable. Taking logarithms on both sides of equation (1), we can conclude that:

$$lnC = f(y, w) + ln\, u_c + ln\, v_c \tag{2}$$

where f represents the functional form chosen and the term $ln\, u_c + ln\, v_c$ is treated as a composite error term. In this paper, the cost-efficiency of one company i (EC_i) is calculated as the ratio of the minimum cost necessary to produce the output vector and the cost to the company i, that is,[7]

$$EC_i = \frac{\hat{C}^{min}}{\hat{C}_i} = \frac{exp[\hat{f}(y_i,w_i)]\exp\,(ln\hat{u}^{min})}{exp[\hat{f}(y_i,w_i)]\exp\,(ln\hat{u}_i)} = \frac{\hat{u}^{min}}{\hat{u}_i} \tag{3}$$

The cost-efficiency defined like that it can be considered as the proportion of resources which are used efficiently, so that if EC for a company i is 0.80, this has to be interpreted as meaning that the company is working with an efficiency level of 80% or, similarly, that the level of inefficiency of this company is 20% of its costs. In other words, this company could produce the same amount of products saving 20% of its costs.

The concept of profit efficiency is preferable to the concept of cost-efficiency when trying to assess the overall efficiency of a company, as it takes into account the errors incurred on both the output and input sides. The literature distinguishes, depending on whether or not market power is taken into account, between standard profit efficiency and alternative profit efficiency, but it is the latter that is closest to reality as it supports the possibility that competition is not perfect or that there are differences in the quality of outputs[8] (Berger & Mester, 1997).

If the choice of the market and/or strategy is wrong, revenue inefficiencies occur, reflecting the failure to produce a higher output value for a given level of outputs and a level of input prices. Alternatively, a company may also have revenue inefficiency if the response to the relative prices of the outputs is bad and produces few high-margin products and a large number of low-margin products. Thus, revenue inefficiency is analogous to the cost, since in both cases it causes a net loss of real value, whether the loss is in terms of a lower value of output produced or greater value of inputs consumed.

Revenue efficiency typically is not directly estimated by the difficulties involved, but profit efficiency that

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[7] The range of cost-efficiency is between 0 and 1 and is equal to 1 for the most efficient company that is in the sample chosen. In practice, the efficiencies are usually defined in relation to the most efficient company observed in the sector, rather than in reference to the true cost minimum, because the underlying technology is unknown. Fortunately, for most economic assumptions it is more appropriate to use the concept of relative efficiency rather than absolute efficiency.

[8] Standard profit efficiency considers that both the product markets and inputs are perfectly competitive, while alternative profit efficiency assumes the possibility that this is not so.

includes both cost and revenue efficiencies in its interaction, being, therefore, a much wider concept as it considers the impact of the choice of output vector about costs as revenue.

In contrast to the cost function, the profit function takes profit as the dependent variable instead of costs, and exogenous variables remain the same as the cost function. Thus, the variable level of output is constant, while its price varies freely and affects profit. The profit function so defined is advisable when one or more of the following conditions are present (Berger & Mester, 1997), as in the case that concerns us:

(1) There are substantial differences in the quality of the products or services of companies;

(2) The output is not fully variable, since a company cannot always reach all scales or combinations of possible products;

(3) The goods and service markets are not perfectly competitive, so any company can have some market power over price;

(4) The price of goods and services cannot be measured with certainty.

Thus, the profit function will be defined as:

$$\pi = \pi(y, w, u_\pi, v_\pi) \tag{4}$$

where π is the profit variable, y is a vector of quantities of outputs, w is the vector of input prices, u_π represents the inefficiency that was found to reduce profit and v_π represents the random error. Again, to facilitate estimation of the efficiency it is assumed that the random error and inefficiency are separable from the remainder of the profit function. Taking logarithms on both sides of equation (4), we can conclude that:

$$\ln(\pi + \theta) = f(y, w) + ln u_\pi + ln v_\pi \tag{5}$$

where θ is a constant added to variable profit of all companies and to ensure a positive value for this variable and therefore allow logarithms to be taken.[9] The profit efficiency for one company i (EB_i) is defined here in as the ratio between the company's current profit (π_i) and the maximum level that the most efficient company in the sample could reach (π^{max}), that is:

$$EB_i = \frac{\hat{\pi}_i}{\hat{\pi}^{max}} = \frac{\{exp[\hat{f}(y_i, w_i)]\exp(ln\hat{u}_i)\} - \theta}{\{exp[\hat{f}(y_i, w_i)]\exp(ln\hat{u}^{max})\} - \theta} \tag{6}$$

The profit efficiency defined like that can be considered as the ratio of the maximum potential profit obtained by the company, so that if the *EB* for a company i is 0.80, this has to be interpreted as meaning that, due to excessive costs and/or deficient incomes, the company would be losing 20% of its maximum potential profit. Unlike cost-efficiency, profit efficiency can be negative, as companies can get to waste more than 100% of their profit potential (Berger & Mester, 1997).

Empirical Analysis

Having concretized the efficiency concepts is using in this paper, the next step is to specify how to measure them. To do this must focus on estimation techniques and functional form. The main problem measuring inefficiency behaviors is to separate these from other random factors that affect cost or profit. This paper will use a parametric method, since it fits better with the concepts of cost and profit efficiency discussed above.[10]

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9 The value of the constant θ must be considered when the values of efficiency are calculated.

10 There is no simple rule to determine which method, within parametric models, best describes the true nature of the data. This itself would not be a problem if all the methods reached the same conclusion; but in fact, the estimated level of efficiency is affected substantially by the chosen method (Berger, Timme, & Hunter, 1993).

The availability of panel data allows the use of a distribution-free approach, which does not require an a priori assumption of a particular distribution for the inefficiency term, or require the assumption of independence of the inefficiency term of the regressors. In this method, the regression coefficients are allowed to vary in time to reap the potential effects of changes in technology and the environment. It is also assumed that a given level of efficiency for each company is constant in time, while the random error tends to cancel each over time. The cost and profit functions are estimated separately for each year of the panel data.

The database[11] used in this research consists of 199 companies in the mineral product manufacturing sector in Spain, competing to offer similar products to their customers and to use similar production factors. This study was performed in 2004, 2005, 2006, and 2007.

Selection of Variables

Outputs: y_1 = sales income, y_2 = other operating income, y_3 = index of pollution[12] (estimated from the weighted sum, according to their danger to human health, of the following four gases: CO, CO_2, NO_2, and SO_2 and the emission of particulate matter PM). Both outputs y_1 and y_2 are desirables, which are those that generate income and are the focus of the production process, while y_3 is an undesirable or a negative output, that is, it has no value and causes environmental degradation.

Inputs: (1) equivalent number of full-time employees (price estimated as w_1 = personnel expenses/equivalent number of full-time expenses); (2) materials (price estimated as w_2 = materials expenses/sales income); (3) capital (price estimated as w_3 = amortization + other operating income/fixed assets); and (4) relative pollution index (price estimated as w_4 = index of pollution/average total assets).

Total cost: C = personnel expenses + material expenses + other operating expenses + amortization.

Profit: π = Operating profit.

Table 1 presents the descriptive statistics of the variables of the study between 2004 and 2007.

Table 1

Descriptive Statistics of the Variables: 2004-2007

	Mean	Median	Maximum	S.D.	Coeff. variation
C	14,407	7,578	163,443	21,692	1.51
π	862	407	11,409	1,670	1.94
y_1	11,689	5,855	142,244	18,670	1.60
y_2	108	11	3,487	314	2.90
y_3	1,082,455	834,468	5,237,320	937,399	0.87
w_1	29	28	49	8	0.27
w_2	0.33	0.35	0.74	0.16	0.47
w_3	0.90	0.63	9.16	1.03	1.14
w_4	202	106	4,358	459	2.27

Notes. C, π, y_1, y_2, w_1 in thousands of euros; y_3 in kg.

Functional Form

The most common functional form in the literature for estimation of cost and profit efficiencies is

[11] The database used is SABI, Sistema de Análisis de Balances Ibéricos—a database including economic and financial data over 550,000 Spanish companies and 67,000 Portuguese firms.

[12] Law 16/2000 on the prevention and control of pollution requires that certain industries are technologically suited to meet pollution limits. It has allowed the European Pollutant Release Inventory (EPER) to provide us with emissions data from minerals industries over four analyzed years.

Translog (Christensen, Jorgerson, & Lau, 1973), which is expressed as:

$$lnC_i = \alpha_0 + \sum_{i=1}^{n} \beta_i lny_i + \sum_{j=1}^{m} \gamma_j lnw_j + \frac{1}{2}\sum_{i=1}^{n} \sum_{j=1}^{n} \lambda_{ij} lny_i lny_j + \frac{1}{2}\sum_{j=1}^{m} \sum_{k=1}^{m} \rho_{ij} lnw_j lnw_k +$$

$$i{=}1nj{=}1m\delta\text{ijln}yi\text{ln}wj + \varepsilon i \qquad (7)$$

where $\varepsilon_i = v_i + u_i$, with v_i being the random error term and u_i the inefficiency term. The conditions of linear homogeneity and symmetry have been imposed on the price of inputs.[13] The profit function is almost the same, except for a change in specification: The dependent variable in this case is the profit, π, rather than the cost. Since this function does not contain the price benefit of the outputs it is not necessary to impose the restriction that is homogeneous of degree one in prices. Three models will be estimated. Model 1 will consider two outputs y_1 and y_2, and three inputs w_1, w_2, and w_3; Model 2 will be defined with three outputs y_1, y_2, and y_3 and three inputs w_1, w_2, and w_3, to evaluate the impact on the estimated efficiency of undesirable output (environmental degradation); and Model 3 will include two outputs y_1 and y_2, and four inputs w_1, w_2, w_3, and w_4, to rate the impact on the estimated efficiency of undesirable output as input (Zhang, Bi, Fan, Yuan, & Ge, 2008).

After obtaining the estimated costs and profits, the residuals will contain the values of both inefficiency *u*, and random error *v*, but since it is assumed that the average of random error over time is zero, calculating the average of all residuals collected for each of the companies in the sample will have thus the term *u*, or the estimated inefficiency. When the number of periods in a study is too short, as in this study, it is possible that this compensation of random errors occurs not entirely; in this case, Berger (1993) proposed truncating the values at both ends. But if choose too many periods, individual efficiency could lose some sense, since it is clear that this means that there are no possible changes in management, the environment and other situations that would not be constant over time. Table 2 shows the results of the cost-profit efficiency estimated for the three models. Also, for comparison between models, it also shows the different points of truncation, 0, 1, 5, 10, and 20%.

Table 2

Cost-Profit Efficiency

	Model 1					Model 2					Model 3				
	0%	1%	5%	10%	20%	0%	1%	5%	10%	20%	0%	1%	5%	10%	20%
Mean cost efficiency	0.299	0.471	0.576	0.740	0.793	0.313	0.474	0.577	0.745	0.791	0.339	0.485	0.601	0.735	0.792
S.D.	0.082	0.110	0.122	0.125	0.117	0.083	0.109	0.121	0.121	0.114	0.086	0.109	0.121	0.123	0.116
Coeff. var.	0.274	0.232	0.211	0.169	0.147	0.265	0.229	0.209	0.162	0.144	0.253	0.225	0.201	0.167	0.147
Mean profit efficiency	0.105	0.162	0.212	0.269	0.329	0.164	0.172	0.192	0.257	0.336	0.166	0.173	0.198	0.259	0.332
S.D.	0.159	0.235	0.289	0.352	0.430	0.243	0.251	0.267	0.328	0.437	0.247	0.253	0.277	0.340	0.451
Coeff. var.	1.507	1.453	1.362	1.309	1.308	1.482	1.459	1.389	1.278	1.302	1.489	1.464	1.395	1.312	1.358

The level of cost-efficiency changes significantly depending on the truncation point selected. Thus, in the case of model 1, the cost-efficiency changes from 29.9% to 47.1% when truncation of 1% is used; when using a truncation of 5% and 10%, efficiency increases to 57.6% and 74%, respectively; beyond this point the increase is reduced. This result shows that even after using panel data for four years the random error is not cancelled over time, which affects significantly the estimated efficiency level. However, when go from 10% to 20%

[13] The homogeneity and symmetry conditions are imposed using the input price w_3.

truncation level, the value of efficiency calculated is not altered significantly, so considering that 10% is a reasonable truncation level at which to evaluate the results. Based on this truncation level, cost-efficiency shows an average around 74%, which means that it might be possible to reduce costs by 26% simply by eliminating inefficiencies.

The results of the estimated cost-efficiency and dispersion values are very similar for all three models, and a level of truncation of 10% indicates that most of the inefficiency of these companies is to be considered independent of the model pollution, as well as an output or an input negative.

The profit efficiency again shows a significant variation of the levels of efficiencies depending on the selected truncation level. In the same way that for the cost-efficiencies the change in the level of profit efficiency is not modified in a valuable way when the truncation point goes from 10% to 20%, the results will be evaluated based on three models for a level of truncation of 10%.

The average level of profit efficiency estimated in the three models is about 26% and with a degree of dispersion of relative high values.[14] Again, these companies could increase their profit by 74% on average if they improved the management of their resources, revenue or both.

To evaluate the relationship between efficiency and pollution, companies split the sample into three groups based on the relative pollution index,[15] 20% less pollutants, 20% more pollutants and the rest.[16] Table 3 shows the values of cost and profit efficiencies for 20% of the firms in the sample for less and more pollutants.

Table 3

Cost and Profit Efficiencies for the 20% Least and Most Polluting Companies

	20% least polluting (n = 40)			20% most polluting (n = 40)		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Cost efficiency	0.739	0.731	0.732	0.712	0.721	0.704
S.D.	0.109	0.102	0.108	0.101	0.100	0.103
Coef. variation	0.147	0.140	0.147	0.142	0.139	0.146
Profit efficiency	0.348	0.340	0.345	0.129	0.127	0.134
S.D.	0.325	0.323	0.328	0.221	0.210	0.223
Coef. variation	0.935	0.950	0.950	1.708	1.654	1.658

To test for differences between groups is performed one-way ANOVA with Tukey's posteriori contrasts. This does not show significant differences for the cost models using the chosen criterion to classify companies (p-values equals to 0.254; 0.174, and 0.170, respectively to for the costs model M1, M2, and M3). For all profit models, it is found that the group 3 is significantly different to group 1 and 2 (p-values equals to 0.012, 0.010, and 0.017, respectively to for the profit model M1, M2, and M3). While for these two last groups are not found significantly differences.

Table 4 shows the Spearman correlations between the pollution index and relative cost and profit efficiencies estimated for each of the three models. Cost-efficiencies are both positive and highly correlated and

[14] This level of efficiency is considerably lower than the estimated cost-efficiency, consistent with results obtained for other sectors.

[15] The relative pollution index is equal to the ratio of the "pollution index" and "average total assets" between 2004 and 2007.

[16] Analysis was also carried out by dividing the firms of the sample for 30% and 40% more and fewer pollutants (n = 60 and n = 80 respectively), but the results were not significantly altered.

statistically significant (*p*-values round 0.97), as expected. Similar results are obtained for correlations with profit efficiencies (*p*-values around 0.99). Moreover, as also expected, the correlations between cost and profit efficiencies are positive and also statistically significant (*p*-values around 0.39).

However, the pollution index is not correlated with the estimated cost-efficiencies, but is correlated negatively with estimated profit efficiencies (*p*-values round 0.39). One possible explanation for this result could be that understanding pollution, such as air pollution in our case, in the absence of regulation companies has no incentive, from the point of view of increasing cost-efficiency, to reduce environmental pollution. Nevertheless, the strategies of the companies are becoming more explicit, as they try to send a message to the market of their responsibility for preservation and respect for the environment in their production processes. This fact is highly valued by the market, which is willing to pay a high price for the products of these companies, improving their income efficiency and, consequently, profit efficiency.

Table 4

Spearman Correlation Coefficient Between Relative Pollution Index and Estimated Efficiencies

	Relative Pollution Index	Cost efficiency Model 1	Cost efficiency Model 2	Cost efficiency Model 3	Profit efficiency Model 1	Profit efficiency Model 2	Profit efficiency Model 3
Relative Pollution Index	1.000						
Cost efficiency Model 1	-0.073	1.000					
Cost efficiency Model 2	-0.024	0.976*	1.000				
Cost efficiency Model 3	-0.069	0.971*	0.963*	1.000			
Profit efficiency Model 1	-0.225*	0.397*	0.406*	0.386*	1.000		
Profit efficiency Model 2	-0.248*	0.383*	0.392*	0.384*	0.978*	1.000	
Profit efficiency Model 3	-0.244*	0.391*	0.396*	0.395*	0.971*	0.996*	1.000

Note. * Correlation is significant at the 0.01 level (bilateral).

Discussion and Conclusion

There is growing interest in more developed societies in being careful with the environment, so that it is possible to achieve better environmental performance without sacrificing economic performance. This implements process that minimize the environmental impact of business activities on the environment, while maximizing the effectiveness and efficiency of production systems and generating greater business value. The traditional view believed that any improvement in environmental results inevitably involves an increase in costs and a reduction in efficiency (Porter, 1991). However, many other researchers do not support this assumption and argue that it is possible to reduce environmental pollution and increase efficiency; that is, pollution is a form of economic inefficiency (Porter & van der Linde, 1995; King & Lenox, 2002). This latter approach is in line with the eco-efficiency paradigm which supports the theory that pollution reduction is compatible with increased economic efficiency and coincides with the Porter hypothesis that "pollution is equal to inefficiency".

This study investigates the relationship between environmental and economic performances in the mineral products manufacturing sector in Spain. There have been several works that have addressed this relationship (Elsayed & Paton, 2005; Russo & Fouts,1997; Doll et al., 2000) but always from the perspective of linking economic performance with inefficiencies, focusing on possible efficiencies from the cost side and ignoring the possible inefficiencies from the income side. It is considered that the effects of responsible behavior on the environment are not just about business cost, but also about income, to estimate the efficiency of profits and thus provide empirical evidence of the eco-efficiency paradigm. Thus, environmental performance is approximated by a weighted average of values of five major pollutants (CO, CO_2, NO_2, SO_2, and PM) and economic performance is approximated by cost and profit efficiencies (economic efficiency).

The results reveal relatively high cost-efficiency levels in relation to estimated profit efficiencies, confirming the importance of revenue inefficiencies in the sector analyzed. This difference could be explained because while profit efficiency is based on a comparison with the sample company that best manages maximization of its benefits, cost-efficiency evaluates the result for a given output level, which does not usually correspond to the optimum level. Thus, although being an efficient company in costs for its current level of output, it may not be efficient for its optimal level of output, which most probably involves a different scale and mix of output. In this case, when there is a deviation from the optimal scale production, the profit efficiency estimates better possible inefficiencies (Berger & Mester, 1993). Also, the low correlation, although positive, between the two efficiencies, is also indicative of the partial view that provides cost-efficiency.

The estimation of cost-efficiencies for the companies in the sample divided by pollution grade reveals differences of little relevance between them, though it is slightly higher for the least polluting. However, what is most surprising is that the correlation between the relative pollution index and cost-efficiency is not statistically significant. As discussed above, a possible explanation for this result could be in the concept and measurement of the pollution used. If understand pollution as air pollution measured by issuing a series of dangerous gases, in the absence of regulation and from the point of view of costs, companies will be encouraged to only make changes to their production processes that reduce dangerous gas emissions if it means a reduction in costs. But companies per se will not be motivated to make changes in their production if this improves efficiency, regardless of whether or not they reduce the emission of dangerous gases. Consequently, it can conclude that one cannot say there is a dependency relationship between improving cost-efficiency and an understanding of the environment, as suggested by the paradigm of eco-efficiency and the Porter hypothesis. Therefore, we cannot accept that less pollution is consistent with a reduction in business costs, as affirmed by our work hypothesis H_1: Being responsible for the environment reduces a company's costs.

Instead, the estimate of the profit efficiency of the most and least polluting businesses in the sample reveals important differences, with the cleaner firms being far more numerous (about 34%) than the more polluting ones (around 13%). Furthermore, the correlation between the profit efficiency and relative pollution index is negative and statistically significant (see Table 4). Accordingly, reducing environmental pollution is compatible with an improvement in profit efficiency since the biggest costs, associated with introducing and implanting production processes that reduce waste and harmful substance discharge into the environment, may be compensated by the use of more efficient and effective forms of productive resources and by the elimination of activities that add cost but create no value for the customer. Avoiding environmental pollution will always be less costly than reducing its effects once it has occurred (Porter & van der Linde, 1995).

Second, and most importantly, being respectful with the environment can also have positive effects on corporate income. Society in general is becoming more committed to environmental conservation and customers conscious of the environment are more likely to demand products and services produced in a respectful manner and pay a higher price for them. Likewise, companies may also be more easily differentiated in the market if they offer products or services that respect the environment, thereby increasing their value. All this eventually translates into increased profit efficiency. This result allows us to conclude that, unlike with cost-efficiency, less polluting firms are relatively more efficient in profits. In this case, the results are consistent with the paradigm of eco-efficiency and the Porter hypothesis, that is, less pollution is compatible with more efficient company profit, which confirms our sub-working hypothesis H_2: Being responsible for the environment increases the profit of the company.

In summary, the conclusions of this research only support the main hypothesis of this study (H_0: Being responsible for the environment is positively related to economic efficiency), when economic efficiency is estimated as the profit efficiency, while also accepting, therefore, sub-hypothesis H_2: Being responsible for the environment increases the profit of the company. However, we cannot accept sub-hypothesis H_1: Being responsible for the environment reduces a company's costs.

However, given the particularities of the sector analyzed, similar analyses in other sectors would need to be conducted, as the success of investments in environmental improvements goes through an analysis of internal resources and capabilities of firms and the characteristics of their industrial sector, and this is the only way in which companies can choose the correct environmental strategy (Reinhardt, 1999; Packard & Reinhardt, 2000; Orsato, 2006). Furthermore, it is also advisable to study other economies where there is a high consumer awareness of the environment. This would help to generalize the conclusion of this study.

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