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ENVIRONMENT AND ECONOMIC EFFICIENCY: AN ANALYSIS OF SOME POLLUTING ITALIAN INDUSTRIES

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Environment and economic efficiency: an analysis of some polluting Italian industries

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ABSTRACT: this research presents an extension of the directional distance function model to measure performances for firms which produce a large number of pollutants and operate in different industrial sectors. I use this methodology to estimate productivity indexes on a sample of Italian firms that were forced to declare their emissions to the European Pollution Release and Transfer Register in 2007. A proxy for the environmental regulation's cost is derived and results show a significant impact in term of potential value added lost. Estimations also reveal differences in mean environmental performances among industries; furthermore, the effect of pollution control follows the same path.

Keywords: Directional distance function, Environmental regulation, Polluting industries

JEL Codes: Q50, Q52, Q56

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CONTENTS

INTRODUCTION

In the recent years the attention on environmental protection and sustainability of economic activities is continuously raised. A large number of new constraints are imposed by regulation with the aim of increasing environmental performances, especially of firms involved in such production processes which are characterized by significant production of pollutants. Entrepreneurs and managers, but also stakeholders and consumers, are paying increasing attention on what are called green performance indexes: this increase the demand for scientific research aimed at creating productivity indexes, or more generally performance measures, which take into account both economical and environmental aspects of firms behaviour. Initial idea of the 70's and 80's, when pollution control was considered only as a burden on firms, was partially overcome during the 90's with the so called Porter's hypothesis. The main idea is that emissions are a sign that resources have been used incompletely, inefficiently or ineffectively (Porter and Van der Linde, 1995) then environmental regulation and pollution reduction could be seen as a sort of stimulus for firms to the adoption of new technology. These are so called win – win opportunities when both environmental and economic performance get better and also innovation is stimulated.

This paper presents a methodology relatively new to the Italian context using a big database allowing, intersectoral analysis of firms' environmental performances. Classical models, such as DEA or SFA, do not allow an asymmetric treatment of some outputs, then a different framework must be used in order to obtain consistent efficiency score in presence of pollution. These new approaches allow to discredit firms which increase emission and to credit them for pollution reduction; it is also possible to estimate the total opportunity cost of environmental regulation. The purpose of my paper is to use a theoretically reliable methodology to measure efficiency when both desirable and undesirable outputs are produced and to compare results with a classical model without considering emissions. By elaborating efficiency score and modifying theoretical hypothesis of the model, an estimation of total regulatory impact is derived for some important industrial sectors where environmental protection is significant.

The remainder of this paper is organized as follows: section 1 reviews previous relevant literature on productivity and pollution, section 2 presents the model, the database is described in section 3 and empirical results are shown in section 4.

1. LITERATURE REVIEW

Recent literature on productivity indexes is largely based on the seminal work by Caves *et al.* (1982) where they derive the expression of multilateral productivity indexes starting from a translog production function. The problem of bad outputs was firstly considered in Pittman (1983) where Caves *et al.* (1982) framework[1] was extended through the estimation of a negative shadow price for each pollutant. This estimation could be source of big distortions as was underlined later by Färe *et al.* (1989) or Boyd and McClelland (1999) and then to avoid in part the problem, three different sets of data were used to obtain an estimation of shadow prices. All data were based on the normative compliance costs provided by engineers and on pollution abatement costs. Empirical findings suggested that productivity levels were significantly different when pollutants were taken into account. The main problem of Pittman's approach was that information about abatement costs was rarely disposable and often not very precise: abatement control expenditures miss many aspects such as time spent by managers complying with environmental regulation, redesigning production process or changing the input mix, increasing maintenance and increasing attention into measuring and reporting emissions as Berman and Bui (2001) suggest.

A fundamental step ahead came from Färe *et al.* (1989) who proposed a non-parametric efficiency analysis framework aimed to take into account undesirable outputs using only information about quantities. The assumed classical characterization of the production possibility set with two additional hypothesis of weak disposability and null jointness which are now largely accepted from literature. They proposed a hyperbolic concept of efficiency to asymmetrically treat bad outputs: an extension of the classical DEA methodology, based on a non radial concept of distance that created some estimation problems. They also developed a proxy of total regulation impact by applying hyperbolic productivity indexes under the two different disposability assumptions.

Using a similar methodology Färe et al. (1993) obtained an estimation of pollutants' shadow prices through the exploita-

[1] Caves *et al*. (1982) the multilateral superlative index is defined as the difference between translog multilateral output index and translog multilateral input index.

tion of output distance function properties. More recently Zofio and Prieto (2001) introduce production limits and they analyze manufacturing industries of 14 OECD countries considering only CO2 emissions as bad outputs and Rio's quantitative goals as standards. Ball *et al.* (2004) derive hyperbolic productivity indexes for the case of agricultural outputs, when there exists a relevant environmental impact in term of human health and aquatic life. Bad outputs are identified in term of pesticide's concentration as a measure of the risk for humans and animals in the US states. Cuesta and Zofio (2005) introduced a parametric distance function based on a translog form to estimate the hyperbolic efficiency of a sample of Spanish saving banks.

To overcome non-linearity problems other approaches were proposed in literature as it is summarized in Tyteca (1996, 1997). Scheel (2001) tried to sum up the most used DEA framework to take into account emissions[2]. In particular linear transformations of bad output data such as $f(b) = -b$ or $f(b) = -b + K$ [3] have been often applied, but they lead to a production function that is not representative of the reality. Other kind of transformation such as $f(b) = 1/b$ introduces problems of non linearity, then classical DEA approach is no more sufficient. For a complete review of the literature on DEA models in environmental field see Zhou *et al.* (2008).

In all these cases the idea of distance under efficiency measure could be input or output based, but it remains substantially radial and it does not allow an asymmetrical treatment of some bad outputs. Only in Chambers *et al.* (1996) a new concept of non radial distance is proposed: it was named directional distance function and it has origin by benefit function proposed in a consumer framework. Theoretical properties of that generalization of output and input distance functions were analyzed in Chambers et al. (1998) and Färe and Grosskopf (2000). The power of that tool is the possibility to modify the direction in which to search for the efficient counterpart of each firm: this allows to change the concept of productivity without modifying technology representation via data transformation.

Application of that concept using linear programming method are growing especially in environmental field: Chung *et al.* (1997) analyze paper and pulp mills,

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[2] After that transformation bad output data are inserted among input in a standard DEA model and program gives productivity index which imply a minimization of all input, then also of pollution.

[3] Where K is sufficiently large to ensure that f(b)>0.

Boyd et al. (2002) a small sample of glass US manufacturing firms, Picazo-Tadeo and Prior (2009) and Picazo-Tadeo et al. (2005) consider Spanish ceramic industry, McMullen and Noh (2007) transit buses firms. Furthermore this methodology is applied at aggregate level: when whole industrial sectors are analyzed like in Domazlicky and Weber (2004) for chemicals; Weber and Domazlicky (2001) estimate efficiency at US state level and Kumar (2006) at country level. In some recent papers such as Färe et al. (2005), Kumar and Managi (2010) or Bellenger and Herlihy (2010) some semiparametric versions of that distance are also appearing.

2. MODELLING ENVIRONMENTAL PERFORMANCE: A DIRECTIONAL DISTANCE FUNCTION APPROACH

To model production process when pollutants are jointly produced with good outputs the directional output distance function by Chambers *et al.* (1996) is applied here. Let $x=(x_1,...x_N)\in R_+^N$ be a vector of inputs, $y=(y_1,...y_N)\in R_+^M$ a vector of good outputs and $b=(b_1,...b_N)\in R_+^N$ a vector of bad outputs such as pollutions. Starting from classical assumptions on the technology and input-output sets I assume that undesirable outputs must be jointly produced with good outputs. This hypothesis is called null jointness and in notation:

$$(y,b)\in P(x) \quad \text{and } b=0\rightarrow y=0 \tag{1}$$

Another idea largely accepted is called weak disposability assumption: if there are some outputs which are undesirable it is reasonable to assume that bad outputs could not be reduced without reducing also good outputs. Classical assumption of free disposability does not hold anymore for all outputs, but only for goods. In notation, where $0\le\alpha\le1$ and P(X) is the production possibility set:

- Weak disposability in (y,b)

$$(x,y,b)\in P(X)\Rightarrow(x,\alpha y,\alpha b)\in P(X) \tag{2}$$

- Free disposability in y

$$(x,y,b)\in P(X)\Rightarrow(x,y,\alpha b)\notin P(X),$$
$$\Rightarrow(x,\alpha y,b)\in P(X) \tag{3}$$

Weak disposability implies that good and bad outputs can be proportionately contracted, but only good outputs can be freely reduced without costs.

The directional output distance function (DODF) gives the maximum feasible proportional contraction in bad outputs and expansion in good outputs. DODF is defined on P(X), takes a value equal to 0 for efficient firms which contribute to the frontier identification and increase with inefficiency. Theoretical properties and duality correspondences are explored in Färe and Grosskopf (2000). The directional output distance function is defined as follows:

$$\vec{D}(x,y,b;g_y,g_b) = \max\{\beta : (y,b) + (\beta g_y, \beta g_b) \in P(x)\} \quad (4)$$

where $g = (g_y, -g_b)$ is the directional vector and P(X) is the production possibility set estimated via DEA by solving, for each firm, the following linear problem after fixing a particular directional vector g = (y,-b):

$$\begin{aligned} &\vec{D}_W(x_0, y_0, b_0; y, -b) = \max \beta \\ &s.t. \quad x_0 \geq Xz \\ &(1+\beta)y_0 \leq Yz \\ &(1-\beta)b_0 = Bz \\ &z \geq 0, \beta \geq 0 \end{aligned} \quad (5)$$

In practice directional output distance function re-scales the observed output vector (y,b) on the frontier following the g direction, then (y,-b) in our case.

Applying DODF, production technology is represented in a way that immediately derive from reality, without transformation and every constraints in the estimation of P(X) could be formulated in linear form then DEA framework is immediately applicable.

Starting with Färe *et al.* (1989) is very common to find also estimation of total regulatory for which is necessary to estimate another model under the hypothesis of free disposability. Linear problems remain as in equation 5, but the last equality is replaced by an inequality with an unchanged directional vector:

$$\begin{aligned} &\vec{D}_F(x_0, y_0, b_0; y, -b) = \max \beta \\ &s.t. \quad x_0 \geq Xz \\ &(1+\beta)y_0 \leq Yz \\ &(1-\beta)b_0 \leq Bz \\ &z \geq 0, \beta \geq 0 \end{aligned} \quad (6)$$

In words it is possible to decrease bad outputs without cost: this is equivalent to say that regulation does not exist any more, and by comparing these two sets of results it is possible to create a proxy of the potential good output loss due to regulation. As Picazo-Tadeo and Prior (2009) suggest with that directional vector it takes the following form:

$$RI = \vec{D}_F(x_0, y_0, b_0; y, -b) - \vec{D}_W(x_0, y_0, b_0; y, -b) \quad (7)$$

This indicator can only give a partial proxy of the total cost imposed by environmental regulation, as Zofio and Prieto (2001) underline that methodology measure exactly total regulatory impact, if and only if no regulation exist before: if in some way firms are already forced to consider pollution it is not possible to identify the real free disposable frontier.

All the invisible cost undertaken throughout the years to comply with previous laws and pollution standards could not be measured and then the potential output loss cannot be derived. What is measurable is the visible departure from the actual best practice frontier in the case of weak disposability to an hypothetical free disposable one that is dependent from all previous choices taken under environmental constraints. Bearing that limitation in mind and using a sort of simulated reality, combining results by both set of linear problems it is possible to create a proxy of regulatory impact in term of potential good output lost.

3. DATA

I will estimate productivity indexes for a large set of firms which are forced by law to declare their pollution. Environmental data comes from the European Pollutions Release and Transfer Register (E-PRTR) that collects data on air and water pollutions at plant level for 91 chemicals in some particular sectors[4]. This register is relatively young in comparison with the experience of other country such as US where the TRI (Toxic Release Inventory) was introduced in 1986 and published in 1989.

[4] In Italy 2 substances are not actually produced then only 89 pollutants appear in the database.

The publication of firm level data about industrial chemicals' releases is an outcome of the so called "third wave" of environmental regulation based on information disclosure about pollution generated by each firms. The idea is based on the concept of reputation and public information that should have effect on firms' behaviour as underlined in Caplan (2003). In Europe this process was started in 1996 with the adoption of UE directive 96/16/CE where the so called EPER (European Pollution and Emission Register) was introduced to monitor the release of chemicals in air and water for 2001 and 2004. The register was enlarged with the regulation CE 166/2006[5] and transfer activities were tracked: it take the new acronym E-PRTR with the 2007 data release.

In my analysis only data from the last version of E-PRTR are considered, therefore all emissions are relative to 2007. All data are official and completely freely disposable to the public in all Europe and European institution are working to increase comparability of data among different industrial[6] sector and different

[5] More information is included and also a better classification of industrial activity was introduced, in the previous version of EPER only 6 industrial sectors are explicitly identified.

[6] Comparison between different industrial sector is possible, but some differences in measurement methods impose caution as suggested in Saarinen (2003)b.

country, a field where some problems arise especially in case of new EU members as Saarinen (2003)a underline. Five particular sectors are included: energy generation, metals, minerals (cement, glass and ceramic industry), chemical industry, waste management and other activities such as pulp and paper, breeding, slaughterhouses. From the E-PRTR register one could obtain general data about each single plants, such as name, address, activity code, kind and name of each substances released, but one can read pollution data if and only if quantity exceeds the threshold stated in regulation CE 166/2006, otherwise the cell is empty. Consequently I am able to calculate mixed productivity indexes only if pollution production is higher than the threshold for a specific pollutant, otherwise the quantity of pollution is so small that its effect on environment is negligible. Therefore in the database appear only firms which cause a significant environmental damage: it is important to underline that thresholds are low and in these particular industries only small firms are not forced to declare emissions.

Economical data, essential for the construction of each productivity index comes from AIDA database published by Bureau van Dijk Electronic Publishing, that contains all economical variables derived from balance-sheets at firm level. From that huge amount of information the focus is restricted on output (in the form of value added[7]), labor (total labor cost) and capital (total tangible asset). All values are relative to 2007.

The richness of E-PRTR database creates big computational problems: pollutants are many and some of them are very specific for each kind of activity, then directional distance algorithm loses efficiency because to the high number outputs and the high number of zeros between them.

In all previous literature environmental data comes from specific survey and also thanks to small sample size and specificity of analysis, pollution data are homogeneous and only relative to a small number of pollutants. Here the heterogeneity of industrial sectors and heterogeneity of substances impose to compact pollution information in a unique numerical value, able represent the total impact on environment for each production process.

European regulation helps by establishing a threshold for each substance: under that level emissions are so low that their impact on environment and on public health could be negligible.

[7] Physical quantity are not a good indicator of production because especially chemicals could vary a lot in terms of value also if firms structure and output are very similar.

Table I. *Summary statistics by E-PRTR sector: sample means, standard errors in brackets (million of €, both)*

	E-PRTR activity code					Total
	2	3	4	6	9	Sample
Air Emission	73.54 (37.42)	19.65 (5.29)	155.28 (60.55)	5.04 (2.82)	28.08 (23.81)	72.36 (20.45)
Water Emission	46.85 (25.45)	0.07 (0.07)	77.87 (44.74)	16.86 (9.21)	20.55 (19.8)	39.41 (14.7)
Value added	1468.14 (384.72)	546 (101.64)	517.91 (161.43)	517.33 (142.08)	926.9 (623.89)	852.06 (152.43)
Labour cost	580.28 (158.62)	251.1 (44.22)	312.2 (78.16)	321.71 (106.32)	552.13 (364.95)	411.76 (74.14)
Assets	1569.05 (510.95)	756.8 (141.92)	564.04 (189.56)	1218.58 (609.93)	1166.08 (763.48)	1035.64 (200.32)
N	52	37	51	17	27	184

Source: *elaborations on E-PRTR and AIDA (Bureau Van Dijk)*

Therefore all the analysis are focused on production processes that lead to a significant impact on environment, according to the threshold and to the minimum of production capacities fixed in regulation CE 166/2006.

For my purpose I have choose firms belonging to activity[8] code 2, 3, 4, 6 and 9 in the CE 166/2006 regulation scheme, which correspond respectively to:

· 2.Metal foundry
· 3.Cement, glass and ceramics factory
· 4.Chemical industry
· 6.Pulp and paper mills
· 9.Other activity like leather tanning, textile dyeing, surface treatment using solvents.

Following Cañon-de-Francia *et al.* (2008) I have created an indicator that sums up all pollutants weighting for their toxicity. Resulting index could be seen as a proxy of total environmental impact distinguishing by air or water release means.

The level of toxicity is obtained via pollutant specific thresholds on the base of the following idea: the higher is the threshold's value, the smaller is the relative toxicity:

$$E_i = \sum_{j=1}^{89} w_j q_{ij} \quad (8)$$

where $w_j = 1/T_j$, j indexes pollutants, i indexes firms, T represents thresholds relative to each pollutant and q is the total quantity released. That process is repeated twice for water and air emission

[8] Before last 2007 data publication activity code 6, 7, 8, 9 were grouped among other activity (ex code 6 in the previous version of EPER).

means. Table I shows some descriptive statistics for the variables included in efficiency evaluation, for both total sample and subsamples constructed by activity code declared in E-PRTR protocol.

4. EMPIRICAL RESULTS

Linear problems relative to directional distance function and their free disposable counterparts are been run for each firm, but industrial sectors analyzed are very different from both technological and economical point of view. Then the best way is to run separately for each industrial sectors a frontier estimation to get better directional distance function results. An additional constraint is added to linear programs in order to allow for variable return to scale as results suggest after Simar and Wilson (2002) test.

Two models are run, one using DODF approach (model 1) and another one assuming the same directional vector under free disposability hypothesis[9] (model 2). Of course the two production possibility sets are different, in particular I observe than P(X) relative to model (2) is larger and that imply greater inefficiency in comparison to the regulated set. This finding is consistent to previous results in literature that suggest higher average level of efficiency when pollutions are taken into account. Table II gives the average results from directional output distance function and from model (2) where bad outputs are not an issue. It is important to have in mind that each firm is always compared with its best practice counterpart derived from the subgroup of firms operating in the same sector from an E-PRTR perspective. My results are then comparable among sectors thanks to the industry specific frontier.

In table II some differences in term of technical and environmental efficiency by activity appear and this results is statistically robust also after applying Kruskal-Wallis non parametric tests. Under model 2 average inefficiency scores are higher and also the number of efficient firms is smaller than in model 1. What emerges is the possibility to increase technical and environmental performances of firms which are under E-PRTR. In particular considering the whole sample, if the best technology in each industry was adopted by all firms, the impact on air and water could be reduced by 23% with an equivalent contemporaneous expansion of value added. Separated results by industry are seen in the same table: chemicals, metallurgy and base pharmaceutics seem to be

[9] This is equivalent to the equation (5) where the constraint on bad outputs is dropped.

the sectors where more efficiency could be recovered; paper production is characterized by good environmental performances probably due to a long tradition in environmental standards. To understand which is the total virtual burden from the lack of disposability regarding bad outputs, linear problem 6 is also estimated. As stated in equation 7, by comparing the 2 set of DODF value I have estimated a proxy of the total regulatory impact.

Table II. *Results from directional output distance function by activity*

Ateco 2007	Directional Output distance function			
	Model 1		Model 2	
	Average β	β=0	Average β	β=0
17.Paper and paper products	12.9%	76.5%	49.1%	41.2%
20.Chemicals	35.9%	41.2%	118.1%	11.8%
21.Base pharmaceutical products	26.3%	53.8%	98.6%	15.4%
23.Products from non metal minerals (cement, ceramic, glass)	19.3%	43.8%	60.1%	15.6%
24.Metallurgy	30.2%	39.5%	93.1%	23.7%
25.Metal products	27.8%	50.0%	172.0%	0.0%
Others activity	12.8%	57.1%	77.6%	23.8%
Total sample	23.4%	49.5%	88.2%	20.1%

Source: *own elaborations*

Table III. *Weak disposability vs free disposability: effects in term of potential output lost*

	Regulatory Impact	Million of VA lost
17.Paper and paper product	34.82%	3.32
20.Chemicals	85.43%	2.86
21.Base pharmaceutical products	72.28%	20.46
23.Products from non metal minerals (cement, ceramic, glass)	40.67%	12.55
24.Metallurgy	61.78%	11.44
25.Metal products	139.94%	14.93
Others activity	64.11%	20.33
Total sample	64.66%	12.12

Source: *own elaborations*

Table IV. *Result of DODF by firms' dimension*

	Average β		Regulatory Impact	N
	Model 1	Model 2		
Large	25.10%	69.17%	44.18%	129
Medium	20.50%	145.00%	123.92%	45
Small	14.82%	77.66%	62.20%	10
Total sample	23.42%	88.20%	64.66%	184

Source: *own elaborations*

Table III reports total burden in term of potential good output lost as percentage of value added. By multiplying this RI index and the observed value added in million € I give monetary quantification of the phenomenon.

From Table III clearly emerges the strength of environmental constraints in all sectors where firms are forced to declare emissions: on average value added could be increased of 60% if all constraints, from law and public opinion, will disappear.

Concerning firm's dimensions, my first analysis seems to show that large firms pay less opportunity cost due to regulation. This evidence, from table IV, is in line with Picazo-Tadeo et al. (2005) and confirms a priori expectations on big firms more able to manage complex normative previsions. Significant and interesting differences among dimensional classes emerge and also Kruskal-Wallis tests confirm: small and medium firms are less inefficient in the regulated framework. Nevertheless the cost they pay in term of potential output for environmental constraint seems to be higher. Probably that evidence could be driven by the limited number of small firms in the sample which is due to the definition of E-PRTR and to the duty of declaring emission only if a significant impact on environment exists.

5. CONCLUSION

This paper examines the relationship between technical efficiency and the pollutants production in some Italian industries where environmental regulation is more pervasive. I have extended classical directional output distance function approach to a multiple bad outputs case and I apply an emissions aggregation procedure, essential to optimize computations.

Differently by other works in my analysis a lot of pollutants are considered and two different total emissions indexes are created considering dangerousness of each substance and release means. My paper also face for the first time the problem of undesirable outputs production taking an intersectoral perspective without losing the microeconomic dimension. An opportunity cost of E-PRTR regulation is derived at firm level in term of its potential value added lost.

My results are in line with previous literature: considering bad outputs changes significantly the best practice frontiers and reduce mean inefficiency. Moreover this analysis shows statistically different levels of efficiency and of potential output lost among industries. I can conclude that chemicals and base pharmaceutics pay more in term of potential value added lost than other sector such as paper or cement.

Empirical evidence regarding the dimensional aspect on environmental efficiency and on opportunity cost of regulation, underlines interesting path that should be investigated deeply in a future work, applying a more sophisticate second stage phase.

In summary I can conclude that directional output distance function approach is a reliable and flexible instrument to create productivity indexes in the field of polluting industry.

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