

Sustainable Development Index via Data Envelopment Analysis.

*Un Indice di Sviluppo Sostenibile
attraverso la Data Envelopment Analysis.*

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Riassunto: A partire dagli anni '70 c'è stata una progressiva presa di coscienza delle problematiche ambientali, che è approdata al concetto di sviluppo sostenibile: si teorizza cioè un modello di sviluppo per la cui attuazione i sistemi economici richiedono indici di crescita positivi e nel contempo l'ambiente richiede equilibrio e stabilità. In questo contesto, la maggior parte degli Stati si è posta l'obiettivo dell'efficienza sia da un punto di vista economico-produttivo che da un punto di vista ambientale. Scopo del presente lavoro è quello di definire un modello per la misurazione dell'eco-efficienza delle province italiane, in un'ottica di sviluppo sostenibile che tenga conto di variabili sia dannose che benefiche per l'ambiente. In particolare, si propone una variante del metodo non parametrico DEA che include variabili ambientali positive e negative.

Keywords: Sustainable Development, Data Envelopment Analysis (DEA), Undesirable outputs, Environmental benefits.

1. Introduction

In 1987, a World Commission on Environment and Development (WCED) report brought the concept of sustainable development into the purview of governments and publics around the world. According to it, sustainable development is “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. During the last decade, political leaders have increasingly come to refer to the idea of sustainable development as an objective of the government activity. This concept intimate a vision of an ecologically balanced society: for most world leaders, it is clear that it is necessary to preserve environmental resources and integrate economics and environment in decision-making.

The emergence of the idea of sustainable development has intensified the need for indicators which capture the link between the economic, social and environmental dimensions. Hence, there is an increasing need for taking account of the impact of organizations of all kinds on environment.

In the context of growing concern over the global environment and related quality of life issues, the purpose of this article is to examine the ecological efficiency of Italian provinces for 2003. This can be made by parametric or non parametric approaches to efficiency frontier estimation, which have very different underlying structures and which can give rise to different efficiency estimate.

In this work our objective is to apply the non parametric techniques, such as Data Envelopment Analysis (DEA), to the field of environmental studies. We try to solve the problem caused by the joint production of good and bad outputs in the traditional measures of efficiency: to rate the performance of a DMU, we propose therefore a variant of the linear programming technique DEA, that includes the presence of desired environmental effects and environmental harms.

The paper is organized as follows. Section 2 presents some of the theoretical background, Section 3 shows a case study which refers to Italian provinces and discusses the results obtained.

2. Method

Data Envelopment Analysis is a non parametric method based on linear-programming techniques developed by Charnes, Cooper and Rhodes (1978). It measures the relative efficiency of a set of several DMUs in their use of multiple inputs to produce multiple outputs.

In the DEA approach to efficiency evaluation we take the observed input and output values and we form a production possibility set (PPS) making certain assumptions; the distance of a DMU from the frontier of this set is then used as a measure of its efficiency. Hence, this method provides a scalar measure of the relative efficiency of each unit, which indicates how much each input can be radially reduced (or output increased) to produce an efficient outcome. Banker (1993) also develops a statistical foundation for DEA by identifying conditions under which DEA estimators of the best-practice production frontier and technical efficiency are consistent and maximum likelihood estimators.

This methodology is frequently applied in many areas of applied sciences, but only a few authors have used it to measure the performance in the environmental field. DEA has to be modified to the context of environmental performance: we now extend the analysis to include the presence of desired environmental effects and environmental harms.

Environmentally harmful variables are a kind of negative outputs, that could be produced together with desirable outputs, such as pollutants emissions generated in air or in water, waste, complications of medical operations, etc. In our model, we treat the environmentally undesirable variables as a special kind of outputs and we include them as inputs, while also seeking to minimize them.

We also consider the presence of environmentally beneficial variables: examples of this variable are reuse and recycling of packaging or materials (rather than their disposal in nature), the use of biodegradable packaging materials, non-freon propellants in aerosols, the generation of solar energy, wind and wave power, etc.

We introduce a performance measure that credits the reduction of undesirable outputs while simultaneously crediting increases in desirable outputs. The model to measure ecological efficiency is formulated in the same way as the model used to determine

technical efficiency, and variables that impact on the environment will be included directly into the linear programming formulation.

We use a CCR model, which is built on the assumption of constant return to scale of activities, under input reduction (which objective is to minimize inputs while producing at least the given output levels).

The relative efficiency of a DMU j_0 is now obtained from the following model:

$$\begin{aligned}
 &\text{Min } \theta \\
 &\text{subject to} \\
 &\sum Y_j \lambda_j \geq Y_0 & (1) \\
 &\sum E_j \lambda_j \geq E_0 & (2) \\
 &\theta X_0 - \sum X_j \lambda_j \geq 0 & (3) \\
 &\theta H_0 - \sum H_j \lambda_j \geq 0 & (4) \\
 &\lambda_j \geq 0, \text{ all } j, & (5)
 \end{aligned}$$

where X_j is the input for DMU j , Y_j is the corresponding output, H_j is the vector of environmental harmful variables, E_j is the vector of environmental beneficial variables, λ_j are the weights of DMU j and θ is the shrinking factor.

The DMU currently rated is inefficient or dominated if there exists a composite DMU that requires fewer inputs and fewer harmful effects to produce the same or greater outputs and the same or greater environmental benefits. If no such weights exist, the DMU is un-dominated and it is located on the efficiency frontier.

3. Case Study

We applied the proposed methodology for evaluating the performance of all 103 Italian provinces for the year 2003. For this propose, we used three categories of factors: inputs, desirable outputs and undesirable outputs.

We regarded the number of employees as an input (X) and the gross domestic product as an output (Y). We considered two undesirable outputs (H_j), which contribute to air pollution: nitrogen dioxide (NO_2) concentration and PM10 concentration, that is concentration of suspended particulate matters; both of them are measured in $\mu\text{g}/\text{mc}$. The two variables selected to reflect the environmentally beneficial effects in the provinces are percentage of separate refuse collection on total waste produced and public parks and gardens, measured in mq/ha .

Data for environmental variables were extracted from the publications “Rapporto 2004 sulla qualità della vita in Italia” and Ecosistema Urbano 2005 di Legambiente; other data were obtained from Istituto G.Tagliacarne.

For our analysis, we divided the provinces into four groups, according to geographical location and we used DEA-Solver, a software package developed by Kaoru Tone. For each province, the relative efficiency scores are listed in the table below (Table 1).

As it can be noted, in Southern Italy 11 units form the efficient frontier. One province, Taranto, is very close to the frontier having the efficiency rating of 0.99, while several of the others do not receive very high scores; Salerno, Agrigento and Messina show the worst scores. In Central Italy 10 provinces are CCR-efficient; particularly noteworthy is

the modest performance of Frosinone. Evaluation of DMUs in Northern Italy by means of our model shows that in the North East 7 units are at the top of the ranking, followed closely by Piacenza, while in the North West 6 provinces obtain the best score and the bottom performers are Torino, Novara e Genova. In both sets, many DMUs receive good efficiency scores.

The application of the modified DEA model to the Italian provinces lead to the conclusion that they are performing quite well, although there is room for improvement. These results are preliminary and they could be improved. First of all, we could include in our analysis more variables: for example, other undesirable outputs in form of pollutants emissions or other environmentally beneficial variables, such as recycling of materials, surface for pedestrian walkway, etc. Secondly, we could use a parametric method for the estimation of production frontiers, such as stochastic frontiers (SF), for estimating the relative efficiencies of the provinces, and then compare the results from both DEA and SF approach.

Table 1: Relative efficiency scores by provinces

South	Score	TA	0,990	AV	0,666	RI	1	PU	0,761	RA	1	PC	0,998	SO	1
CT	0,876	CA	1	PA	0,628	GR	1	MC	0,684	VE	0,893	PD	0,749	VA	0,993
CH	1	AQ	1	TP	0,603	VT	1	AN	0,657	BZ	0,859	N-West	Score	PV	0,618
CL	1	NU	0,608	RC	0,594	AP	0,650	PG	0,613	PR	0,817	AO	1	MI	0,842
OR	0,729	RG	0,644	AG	0,499	AR	0,966	FR	0,414	PN	0,813	VC	0,653	LC	1
TE	1	VV	0,865	NA	0,598	LT	0,963	N-East	Score	FC	0,793	BI	1	VB	1
LE	1	BA	1	ME	0,500	PT	1	TV	0,928	BO	0,784	AT	0,669	CO	0,732
PZ	1	SR	0,764	FG	0,657	LU	1	RO	1	RN	0,787	MN	1	BS	0,791
SA	0,423	SS	0,780	CS	0,602	Roma	0,870	BL	1	VR	0,754	CR	0,754	LO	0,860
CE	0,887	EN	0,608	Center	Score	MS	1	UD	1	RE	1	IM	0,985	BG	0,805
KR	1	BN	0,810	TR	1	SI	0,883	GO	1	FE	1	SV	0,979	GE	0,582
PE	0,812	CZ	0,622	PO	0,761	PI	1	TS	0,974	VI	0,834	SP	0,968	AL	0,598
MT	1	BR	0,730	LI	1	FI	0,859	TN	0,892	MO	0,687	CN	0,964	TO	0,540

References

- Banker R.D. (1993) Maximum likelihood, consistency and data envelopment analysis: a statistical foundation, *Management Science*, 39, 1265-1273.
- Charnes A., Cooper W.W., Rhodes E. (1978) Measuring the efficiency of decision making units, *European Journal of Operational Research*, 2, 429-444.
- Dyckhoff H., Allen K. (2001) Measuring ecological efficiency with Data Envelopment Analysis (DEA), *European Journal of Operational Research*, 132, 312-325.
- Dyson R.G., Allen R., Camanho A.S., Podinovski V.V., Sarrico C.S., Shale E.A. (2001) Pitfalls and protocols in DEA, *European Journal of Operational Research*, 132, 245-259.
- Kuosmanen T., Kortelainen M. (2004) Data Envelopment Analysis in environmental valuation: environmental performance, eco-efficiency and cost-benefit analysis, University of Joensuu, *Discussion Papers in Economics no.21*.
- Nissi E., Rapposelli A. (2005) Assessing ecological efficiency via Data Envelopment Analysis, *Atti Convegno Intermedio SIS 2005*, 171-174.
- Schell H. (2001) Undesirable outputs in efficiency valuations, *European Journal of Operational Research*, 132, 400-410.
- Thore S.A. (2002) *Technology commercialization: DEA and related analytical methods for evaluating the use and implementation of technical innovation*, Kluwer Academic Publishers, Boston.
- World Commission on Environment and Development (1987) *Our common future*, Oxford University Press, Boston.