European Journal of Operational Research 207 (2010) 1027–1040

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Innovative Applications of O.R.

Comparing frontier methods for economic–environmental trade-off analysis

Van Meensel Jef [a,*], Lauwers Ludwig [a,b], Van Huylenbroeck Guido [b], Van Passel Steven [c]

[a] ILVO, Social Sciences Unit, Burg. Van Gansberghelaan 115, B-9820 Merelbeke, Belgium
[b] Ghent University, Department of Agricultural Economics, Coupure Links 653, B-9000 Ghent, Belgium
[c] Hasselt University, Faculty of Business Economics, Agoralaan, B-3590 Diepenbeek, Belgium

ARTICLE INFO

Article history:
Received 13 January 2009
Accepted 19 May 2010
Available online 23 May 2010

Keywords:
Economics
Environment
Trade-off analysis
Frontier methods
Production function
Pig finishing

ABSTRACT

This paper uses a mechanistic frontier approach as a reference to evaluate the ability of conventional parametric (SFA) and non-parametric (DEA) frontier approaches for analyzing economic–environmental trade-offs. Conventional frontier approaches are environmentally adjusted through incorporating the materials balance principle. The analysis is worked out for the Flemish pig finishing case, which is both representative and didactic. Results show that, on average, SFA and DEA yield adequate economic–environmental trade-offs. Both methods are good estimators for technical efficiency. Cost allocative and environmental allocative efficiency scores are less robust, due to the well-known methodological advantages and disadvantages of SFA and DEA. For particular firms, SFA, DEA and the mechanistic approach may yield different economic–environmental trade-offs. One has therefore to be careful when using conventional frontier approaches for firm-specific decision support. The mechanistic approach allows for optimizing performances per average present finisher, which is the production unit in pig finishing. Conventional frontier methods do not allow for this optimization since the number of average present finishers varies along the production functions. Since the mechanistic production function is based on underlying growth, feed uptake and mortality functions, additional firm-specific indicators can also be calculated at each point of the production function.

1. Introduction

The rationale for taking into account environmental issues in production analysis exists already for some decades. Various types of integrated economic–environmental performance measurement combine the assessment of environmental burden and economic utility. Three main types of modeling can be distinguished: eco-efficiency ratio indicator measurements (e.g. Dahlström and Ekins, 2005; Hellweg et al., 2005; Scholz and Wiek, 2005), environmentally adjusted productive efficiency models (see reviews by Scheel, 2001; Tyteca, 1996) and frontier eco-efficiency models (Huppes and Ishikawa, 2005; Kuosmanen and Kortelainen, 2005; Quariguasi Frota Neto et al., 2008; Quariguasi Frota Neto et al., 2009). The last two types imply frontier analysis methods (see reviews by Charnes et al., 1995; Coelli et al., 2005; Cooper et al., 2000; Greene, 1993; Kumbhakar and Lovell, 2003; Ray, 2004). Their ability to account for environmental issues is discussed by Lauwers (2009).

Although these methods are based on activity analysis, the question rises whether they sufficiently allow for economic–environmental trade-off analysis, in particular for planning purposes. Taking the right decisions is not straightforward, since multiple factors may influence economic and/or environmental performance. A clear view on firm-specific trade-offs between economic and environmental performance is nevertheless indispensable for good decision making.

Typically, trade-offs between economic and environmental performance are presented by a marginal abatement cost curve. Conventional theory bases the marginal abatement cost curve on two assumptions: (1) firms are producing fully efficiently and (2) production and pollution abatement are separable. Pollution is then considered as a fixed proportion of a firm's output. This strict joint production relation (Whitcomb, 1972) implies weak disposability for pollution. Weak disposability means that a firm can only control its pollution by reducing outputs and pollution proportionally (Shephard, 1970) or by investing in pollution control equipment. A decrease of only pollution is then always costly and leads to a negative economic–environmental trade-off.

* Corresponding author. Tel.: +32 9 272 23 59; fax: +32 9 272 23 41.
E-mail address: jef.vanmeensel@ilvo.vlaanderen.be (J. Van Meensel).

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doi:10.1016/j.ejor.2010.05.026

Numerous authors (e.g. Archibald, 1988; Hill et al., 1999; Rennings, 2000; Wossink et al., 2001) argue that production, pollution and abatement are to be treated as non-separable. This means that pollution control can also be achieved by changes in production practices. In addition, the renewed theoretical paradigm states that production is not always efficient: using inputs more efficiently may lead to the achievement of both economic and environmental objectives simultaneously. Picazo-Tadeo and Prior (2009) show that, under the assumption of weak disposability of pollution, inefficient firms may improve efficiency, leading to a better economic performance without affecting environmental performance. De Koeijer et al. (1999, 2002) even show that using inputs more efficiently may improve simultaneously economic and environmental performance. In order to achieve this economic–environmental win–win, the weak disposability assumption for pollution has to be relaxed: environmental improvement does not always imply private costs. If economic and environmental performances improve simultaneously, a positive trade-off is established.

The objective of this paper is to evaluate the ability of parametric (Stochastic Frontier Analysis, SFA) and non-parametric (Data Envelopment Analysis, DEA) frontier approaches for analyzing positive and negative economic–environmental trade-offs and enabling decision support. The analysis is worked out for the Flemish pig finishing case, which is representative for industries facing environmental problems and which is also interesting from a didactic perspective. Moreover, the pig finishing case allows for reconstructing a reference production function in a mechanistic way. The mechanistic approach starts from empirical agronomic knowledge and combines growth, feed uptake and mortality functions. The mechanistic approach yields extra information for evaluating the ability of SFA and DEA for analyzing trade-offs.

The environmental effect that is focussed on is nitrogen pollution. Based on the materials balance principle, nitrogen excretion from pig finishing is calculated as the amount of nitrogen entering the pig finishing activity in inputs minus the amount leaving the activity under the form of useful output.

Section 2 describes the pig finishing case. Section 3 presents the environmentally adjusted SFA and DEA approaches that allow for measuring technical, cost and environmental efficiencies. Section 3 also provides a short summary of literature comparing efficiency scores obtained with parametric and non-parametric approaches. The mechanistic approach is presented in Section 4. In Section 5, the distinguished approaches are applied to the data sample of pig finishing farms and the assessed economic–environmental trade-offs are analyzed. Finally, Section 6 concludes.

2. The pig finishing case

Pig finishing in Flanders is a representative case for industries that aim at remaining cost competitive and profitable under the sharpened limiting condition of producing in an environmentally sound manner. It is also an interesting case because the essential transformation of inputs into outputs can be easily brought down to a "two-input–one-good-output" framework, which enables didactic representations. The good output is pig production, expressed here as kilogram live weight. The two main inputs are feed and piglets. As the finishing activity takes about 140 days, more than one piglet per year can be started up to get finished as a marketable pig. Besides piglet costs, also other costs are linked to this starting-up process, so it is more convenient to see rotations (=number of start-ups per year on one pig place) as an input factor instead of the mere piglet input.

The pig place is the technical production unit. In practice, however, a real occupied pig place is more useful as technical production unit. The real occupied pig place can be made operational through the concept of average present finisher (APF), which is a pig place corrected for the actual occupation. The number of APF is easily monitored in most current accounting systems, through regular counting (e.g. every week) or through individual age registration.

The data-driven as well as the mechanistic production functions are estimated with cross-sectional data from 117 pig finishing farms from the Belgian Farm Accountancy Data Network (FADN). Data for three consecutive years are pooled to reduce possible measurement errors, in particular due to substantial stock changes. The time period covers 2001 to 2003. Special attention is paid to the robustness of the data sample. The final sample of 117 farms stems from an initial sample of 126 pig-finishing farms, from which 9 outliers have been removed. The final sample does not contain farms with outlying values for the main technical key figures, inferior scale and substantial structural changes during the time period 2001–2003. The FADN data sample provides all necessary input and output data, other key figures and price information. Nitrogen content data are average values from literature.

Table 1 presents descriptive statistics for the sample of 117 farms. Under Belgian production conditions and for the examined time period 2001–2003, pig finishing starts with a 10 week old piglet and ends with a marketable pig of about 109 kilogram. The process can be repeated about 2.5 times a year on one pig place. Finishing pigs gain about 0.6 kilogram a day and use approximately 3 kilogram of

Table 1
Descriptive statistics for the sample of 117 pig finishing farms.

Key figure	Average	Standard deviation	Minimum	Maximum	Median
Live weight production (kilogram/APF.year)	268	24	210	330	265
Feed input (kilogram/APF.year)	660	47	560	779	660
Number of rotations (#/APF.year)	2.55	0.23	2.01	3.09	2.55
Pig finishing scale (APF)	758	417	86	2024	660
Delivery weight (kilogram live weight)	109	4	99	118	109
Finishing period (days)	147	14	120	186	146
Average daily weight gain (kilogram/day)	0.593	0.050	0.471	0.743	0.590
Feed conversion (kilogram feed/kilogram weight gain)	3.06	0.18	2.69	3.60	3.04
Mortality rate (%)	4.30	1.80	0.91	8.88	4.05
Feed price (euro/kilogram)	0.189	0.012	0.145	0.246	0.188
Rotation price (euro/rotation)	40.3	4.3	30.1	51.6	39.7
Pig price (euro/kilogram live weight)	1.13	0.04	0.94	1.24	1.13