Performance measurement in wastewater control – pig farms in Taiwan

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Abstract

Using a DEA approach this paper assesses the performance of wastewater treatment from pig farms in Taiwan. The results indicate that most pig farms have decreasing returns to scale. The average value of scale efficiency for the sample of pig farms is 0.901, and the pure technical efficiency is 0.821. These efficiency values indicate that most pig farms may improve performance of wastewater treatment through the adjustment of control equipment scale and increasing wastewater treatment efficiency. Moreover, the main cause of scale inefficiency is decreasing returns to scale, which means that increasing investment in pollution control may not provide a corresponding increase of wastewater treatment efficiency. Based on the farm size, it is found that larger pig farms usually have higher values of efficiency. In addition to the farm size, other factors affecting the environmental efficiency are also analyzed and discussed.
Keywords: pig farm, effluent regulation, environmental performance, data envelopment analysis (DEA).

1 Introduction

The hog industry is Taiwan's most important livestock industry. However, it is also the main cause of livestock water pollution. It is estimated that the daily quantity of biochemical oxygen demand (BOD) from wastewater is about 4,223 tons in Taiwan, and of this, livestock wastewater contributes 673 tons (16%) [1].

To regulate the water pollution caused by livestock industry, the Environmental Protection Administration (EPA) of Taiwan has implemented

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effluent standards, which are composed of BOD, chemical oxygen demand (COD), and suspended solids (SS), with maximum levels of 80, 600, and 150mg/l, respectively. To ensure their discharge meets the effluent standards, pig farms must construct wastewater treatment facilities, the so-called Three-Stage Wastewater Treatment System. However, pig farmers argue that the effluent standards are too rigorous to comply with. From the viewpoint of authorities, polluters are required to comply with the regulation. Nevertheless, the effluent standards are not easily met, and it is likely that violations may occur. Consequently, the goals of the regulation may not be achieved, and the regulatory agencies and the farmers are often in conflict.

In this context, it is important to explore the operational efficiencies of wastewater treatment facilities among different pig farms. By analyzing the relationship between inputs and outputs of wastewater control for pig farm sample, this study uses a nonparametric approach to inspect the pig farms' ability and performance in operating wastewater control. Thereby the technical and scale efficiencies on pollution abatement for pig farms can be calculated. A regression analysis is further used to test the relationship between efficiency values and the affecting factors. Then, the policy implications of improving the environmental performance of wastewater control may be derived.

2 Methods

The DEA has been widely used to assess the comparative efficiencies of homogeneous operating units such as banks, hospitals, and farms and so on. These units of assessment are usually termed as decision making units (DMUs), as termed by Charnes *et al.* [2]. By calculating Shephard's distance function [3], a conventional model can be applied to estimate various efficiencies via input or output orientation (e.g., [2, 4]).

Based on Luenberger's benefit functions [5], Chambers *et al.* developed a more generalized directional distance function to modify the traditional model [6]. Consider a single input (x) and a single output (y) production mix as illustrated in Figure 1, where DMU k is inefficient and can be projected onto the efficient bundle c (or bundle e) through an input (or output) orientation. Alternatively, any point between c and e, e.g. bundle d, could be the projected point when the directional distance function is used.

Consider a data set relating to N pig farms. For any individual farm k (k=1,…,N), let y_k denotes its $S\times 1$ output vector, x_k its $M\times 1$ input vector, respectively. For all farms, Y denotes their $S\times N$ output matrix, and X the $M\times N$ input matrix, respectively. Thus a DEA model based on directional distance function is formulated as follows [7]:

$$\begin{aligned} &\underset{\theta,\lambda}{Max}\,\theta \\ &s.t. \quad \begin{aligned} &Y\lambda-(1+\theta)y_k \geq 0 \\ &(1-\theta)x_k - X\lambda \geq 0 \\ &\lambda \geq 0 \end{aligned} \end{aligned} \tag{1}$$

where θ is a scalar, and λ is an $N \times 1$ vector of intensity variables to ensure convexity of the production set. The calculated θ^* is the value of directional distance function, and the technical efficiency TE_{CRS} is then defined in terms of $1/(1+\theta^*)$ [7]. Model (1) is referred to as a CRS (constant returns to scale) technology. It can be easily modified to account for VRS (variable returns to scale) by adding constraint $I\lambda=1$ to model (1) [8], where I is a $1\times N$ vector of ones, and the pure technical efficiency TE_{VRS} can be calculated by a revised model. The ratio of TE_{CRS} to TE_{VRS} represents the scale efficiency (SE):

$$SE = TE_{CRS} \big/ TE_{VRS} \tag{2}$$

when the SE value is less then one, indicating a divergence between the efficiency rating of a pig farm under CRS and VRS, and the impact of scale size is caused either by increasing or decreasing returns to scale (IRS or DRS). By using non-increasing returns to scale (NIRS) frontier [8], IRS and DRS can be distinguished. In fact, adding a constraint $I\lambda \leq 1$ to model (1), its corresponding technical efficiencies TE_{NIRS} can then be estimated. As illustrated in Figure 1, the efficient frontiers for CRS, VRS, and NIRS are along the segments *obc*, *abce*, and *obce*, respectively. A pig farm has CRS if the TE_{CRS} value is equal to the TE_{VRS} value. If these two values are not equal but $TE_{NIRS}=TE_{VRS}$, then DRS is identified, otherwise the operation of control equipment is IRS.

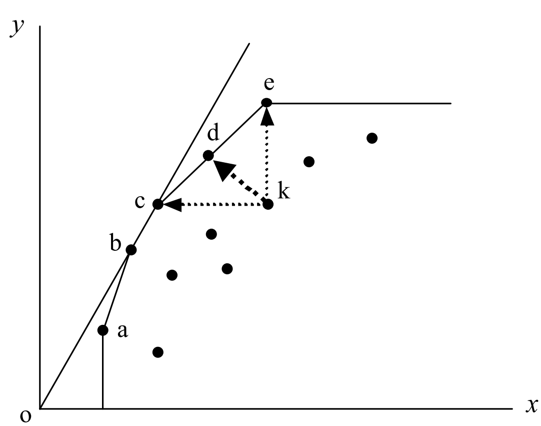

Figure 1: Illustration of IRS, CRS, and DRS.

3 Three-stage wastewater treatment system

The prevailing wastewater control equipment for pig farms in Taiwan is the so-called 'Three-Stage Wastewater Treatment System (TSWTS), which consists primarily of solid/liquid separator, anaerobic fermentation tank, and aerobic fermentation tank. In order to collect wastewater, a raw tank ahead of the

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solid/liquid separator is required; and after the process of aerobic fermentation, a sediment tank is installed to further collect sludge. A flow diagram of the TSWTS is shown in Figure 2.

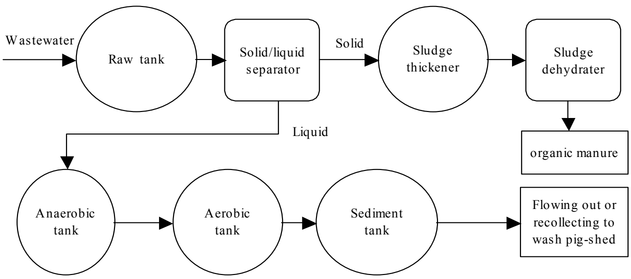

Figure 2: Flow diagram of TSWTS.

4 Data

Based on two projects co-sponsored by the EPA and the Council of Agriculture that were completed in 2003 and 2004, respectively, this paper took 31 pig farms as objects of study. Wastewater was drawn bimonthly from the raw tank and the sediment tank for inspecting the concentrations of BOD, COD, and SS. The differential values between raw and sediment tank are the output data, while the input data include investment in wastewater control equipment, operation and maintenance costs, and work hours for operating. Galanopoulos *et al.* [9] indicated that if inputs can be shared by per head of sow, then the DRS of control equipment in a small farm may be reasonably explained. Hence the input data in this study have been expressed as per head of sow.

Though the difference of before and after wastewater treatment can represent the degree of pollution reduction and to some extent may denote the effectiveness of control equipment operation, the differential value itself does not guarantee the correspondence of regulated standards. Therefore, BOD, COD, and SS are combined in this paper to check the pass ratio of total inspections.

5 Results and discussion

The estimated results of wastewater treatment performance for 31 pig farms are illustrated as in Table 1. There are 4 (12.9%) and 8 (25.8%) pig farms that reach the efficiency frontier under CRS and VRS assumptions, respectively.

According to the returns to scale of wastewater treatment, pig farms can be identified as IRS, CRS, and DRS and the respective numbers are 7 (22.6%), 4 (12.9%), and 20 (64.5%) (Table 2). The average values of TE_{CRS} and TE_{VRS} for pig farms with DRS are lower than those with IRS and CRS. It should be noted that the proportion of pig farms with DRS is about 65%. The large proportion of pig farms identified with DRS and failing to meet the effluent standards implies that other pig farms may have even more difficulty complying with the regulations.

Table 1: Environmental efficiency values and returns to scale.

DMU	TE_{CRS}	TE_{VRS}	SE	RTS*	DMU	TE_{CRS}	TE_{VRS}	SE	RTS
1	0.609	0.685	0.889	IRS	17	0.783	0.980	0.799	DRS
2	0.656	0.690	0.950	IRS	18	0.763	1	0.763	DRS
3	1	1	1	CRS	19	0.591	0.639	0.925	DRS
4	1	1	1	CRS	20	0.593	0.632	0.938	DRS
5	0.703	0.865	0.813	DRS	21	0.578	0.588	0.983	DRS
6	0.578	0.591	0.977	DRS	22	0.990	0.998	0.992	IRS
7	0.642	0.909	0.707	DRS	23	0.753	1	0.753	DRS
8	0.608	0.692	0.879	DRS	24	0.612	0.626	0.979	DRS
9	0.664	0.846	0.785	DRS	25	0.686	0.926	0.741	IRS
10	0.710	0.776	0.915	DRS	26	0.730	0.888	0.822	DRS
11	1	1	1	CRS	27	0.601	0.652	0.922	DRS
12	1	1	1	CRS	28	0.665	0.665	0.999	IRS
13	0.872	1	0.872	IRS	29	0.600	0.617	0.973	DRS
14	0.582	0.595	0.979	DRS	30	0.798	0.912	0.876	DRS
15	0.822	0.842	0.977	DRS	31	0.660	0.824	0.801	IRS
16	0.937	1	0.937	DRS	mean	0.735	0.821	0.901	

* RTS: Returns to scale, IRS: increasing returns to scale, CRS: constant returns to scale, DRS: decreasing returns to scale.

Table 2: Average efficiency values of RTS.

	IRS	CRS	DRS	F value	P value
TE_{CRS}	0.734	1	0.682	14.913	0.000
TE_{VRS}	0.827	1	0.783	3.667	0.039
SE	0.892	1	0.885	3.013	0.065
No. of farm (%)	7 (22.6)	4 (12.9)	20 (64.5)		

To test whether farm size may affect the performance of environmental efficiency, the sample was divided into three groups, i.e. 13 farms (41.9%) with less than 100 sows each, 9 farms (29.0%) with 101~200 sows each, and 9 farms (29.0%) with more than 201 sows each. The results indicate that with larger farms, there are higher values of environmental efficiency (Table 3).

Table 3: Average efficiency values of three different farm size.

No. of sow	≤ 100	101-200	≥ 201	F value	P value
TE_{CRS}	0.652	0.75	0.84	5.729	0.008
TE_{VRS}	0.77	0.821	0.893	1.663	0.208
SE	0.866	0.918	0.936	1.89	0.17
No. of farm (%)	13 (41.9)	9 (29.0)	9 (29.0)		

Furthermore, the relationships of farm size and RTS are analyzed in Table 4. It can be seen that all small farms (less than 100 sows) are DRS, and the larger farms have higher percentages of CRS and IRS. This may imply that the pollution control cost per head of sow is lower for larger farms, which is an advantage for RTS.

Table 4: Contingency table of farm size and RTS.

No. of sow	IRS	CRS	DRS	Chi-Square Test
≤ 100	0 (0)*	0 (0)	13 (100)	Chi-Square=15.06
101-200	3 (33.3)	1 (11.1)	5 (55.6)	P value=0.005
≥ 201	4 (44.4)	3 (33.3)	2 (22.2)	

* Numbers in parentheses are percentage values.

Table 5: Factors affecting control performance using Tobit model.

variable	TE_{VRS}		SE	
	coefficient	t value	coefficient	t value
constant	0.4260 **	2.144	0.8449 **	6.884
no. of sows on farm	0.0002	0.805	0.0003 *	1.86
whether shotes are sold	0.2116 **	2.245	0.0166	0.305
temperature of farm location	-0.0219	-0.567	0.0146	0.605
local characteristics of the farm location	0.0305	0.285	-0.0104	-0.16
quantity of treated wastewater collected	-0.0001	-0.123	0.0014 **	2.433
whether the anaerobic tank is clean	-0.0181	-0.272	0.0071	0.172
education years of operator	0.0809 **	3.000	-0.0064	-0.394
years of experience in operating	0.0068	0.829	-0.0011	-0.225
having training within 5 years	0.0354	0.564	-0.0400	-1.006

** Significant at 5% level;* significant at 10% level.

In addition to the RTS factor, other factors may also affect the performance of wastewater control, e.g. no. of sows on farm, the temperature of the farm location, local characteristics of the farm location, quantity of treated wastewater collected, whether the anaerobic tank is clean, the socio-economic conditions of the wastewater operator, etc. To test the impact of these factors on the efficiency values, a Tobit regression model has been used, and the results are shown as Table 5. Some of variables' signs meet the expectations and are statistically significant at the 5% or 10% level, e.g. the number of sows in a farm, whether the farm sells shotes, and the education years of the operator. The reason that higher level of education is conducive to the effective operation of wastewater control equipment may be because the treatment system is complex and requires education-related knowledge.

6 Conclusions

The average TE_{CRS}, TE_{VRS}, and SE for the pig farm sample are 0.735, 0.821, and 0.901, respectively. These results indicate that an average farm in Taiwan may have 26.5% of divergence for Pareto-efficiency in technical efficiency, 17.9% in pure technical efficiency, and 9.9% in scale efficiency.

By testing the RTS of wastewater control, the 31 pig farms are identified as 7 (22.6%) IRS, 4 (12.9%) CRS, and 20 (64.5%) DRS. Since the inspection ratio meeting regulated standards is only 0.56, and most farms are classified as DRS, it is very difficult for these farms to increase their operational efficiency by simply investing in more control equipment.

Several suggestions can thus be made from the above findings and discussion. First, more effective control equipment or techniques need to be developed to replace the current three-stage system. Second, the average size of pig farm should be further increased. Third, the size of pigs should be adjusted in some farms. Last, pig farms should hire operators with higher education or better experience.

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