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Research Article

Efficiency measurement in Two-Stage network structures considering undesirable outputs

A. Amirteimoori * †, A. Toloie-Eshlaghi ‡, M. Homayoonfar §

Abstract

Since data envelopment analysis (DEA) introduced in 1970s, it has been widely applied to measure the efficiency of a wide variety of production and operation systems. Recently DEA has been extended to examine the efficiency of decision making units (DMUs) with two-stage network structures or processes, where the outputs from the first stage are intermediate measures that make up the inputs of the second stage. Many researchers developed several DEA based models for evaluating the efficiencies of such systems. This paper considers evaluation of the general two-stage network structures, while each stage may produce undesirable output, in addition to desirable ones. The developed model is applied to Green Hen poultry chain in Guilan province, Iran.

Keywords : Two-Stage Network; Data Envelopment Analysis; Undesirable output; Efficiency evaluation; Decision Making Unit.

1 Introduction

Modern efficiency analysis begins with seminal work of Farrell [9], who first introduced concepts which measure the efficiency of a set of comparable decision-making units (DMUs) relative to the best practice frontier. Building on Farrell's idea, Charnes et al. [3] introduced a powerful methodology to assess the relative efficiency of multi-input multi-output production units which has titled data envelopment analysis (DEA). Since then, there has been an impressive growth both in theoretical developments and applications of the ideas to practical situations.

Recently, a number of studies have concentrated on measuring the efficiencies of processes with two-stage network structure where in addition to the inputs and outputs, a set of intermediate measures exists between the two stages. These intermediate measures are the outputs from the first stage that become the inputs to the second stage. To address this issue, many researchers have proposed various approaches to network DEA in which the internal structure of the production process is considered when measuring the efficiency. The various forms of two stage networks, depended on the structure of the black box's transformation process, categorized in Figure 1.

Several researchers used network DEA for measuring the efficiency of two-stage structures in various application areas. For example, Wanke [25] used a network-DEA centralized efficiency model to measure Brazilian airports efficiency levels and optimize the stages simultaneously.

*Corresponding author. teimoori@guilan.ac.ir
†Department of Mathematics, Islamic Azad University, Rasht Branch, Rasht, Iran.
‡Department of Management and Economics, Islamic Azad University, Science and Research Branch, Tehran, Iran.
§Department of Management and Economics, Islamic Azad University, Science and Research Branch, Tehran, Iran.

Seiford and Zhu [24] used a two- stage network structure to measure the profitability and marketability of 55 US commercial banks. Kao and Hwang [13] considered 24 non-life insurance companies in Taiwan with a two-stage process of premium acquisition and profit generation. Liang et al. [21] studied two-stage network structure for analyzing the performance of a set of hypothetical supply chains. Yang and Liu [26] integrated a two-stage series performance model and fuzzy multi-objective model to conduct a valid, fair and reliable evaluation on Taiwan's bank branches. Fukuyama and Weber [10] proposed a slacks-based two-stage network DEA model to measure the performance of Japanese banks with bad outputs. Chiu et al. [4] incorporated the concepts of undesirable intermediate, intermediate input, uncontrollable input and undesirable output to the value-chains model, thereby creating a modified value-chains model to compute transit and economic efficiencies in 30 regions of China. Akther et al. [1] studied the performance of 21 banks in Bangladesh and used a two stage network approach for maximizing desirable outputs and minimizing bad outputs. Lozano et al. [21] proposed a directional distance approach to deal with network DEA problems with undesirable outputs and applied their model to the problem of modeling and benchmarking airport operations in Spain. Various existing DEA models for efficiency evaluation of two-stage network structures or processes are reviewed by Cook et al. [5].

In Figure 1, A illustrates a process in which

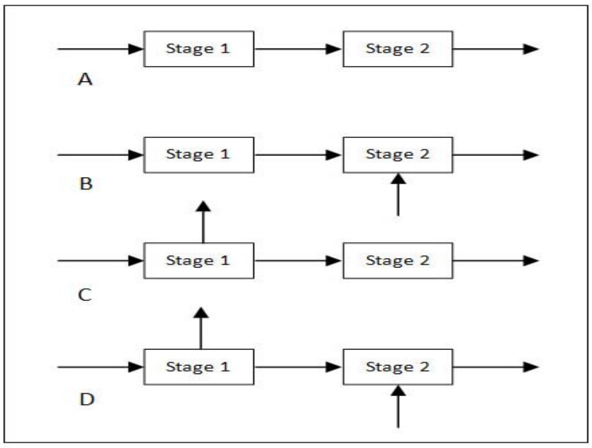

Figure 1: Serial two-stage process of DMU_j.

all the outputs from the first stage (intermediate products) are the only inputs to the second (Lozano [20]), B illustrates a process in which all the outputs from the first stage and additional inputs become the inputs of the second (Li et al. [19]), C illustrates a process in which some outputs from the first stage may leave the system while others become inputs to the second (Cook et al. [6]) and D illustrates a process in which some outputs from the first stage may leave the system, while others and additional inputs consider as inputs of the second stage (Chiu et al. [4])

Note: the outputs of each stage could be desirable or undesirable.

One main limitation of traditional DEA models is the situation in which production process generates undesirable by-products such as wastes and pollutants, in addition to desirable ones. Research on undesirable outputs has also been popularly pursued by DEA. It was first proposed by Fare et al. [7] and has been largely extended in the few past years. A number of studies have been carried out to deal with this type of output. For example, Scheel [22] used a data transformation approach to make undesirable factors desirable so that the resulting model preserves linearity. Using the classification invariance property, Seiford and Zhu [23] used the standard DEA model to improve the performance via increasing the desirable outputs and decreasing the undesirable outputs. Fre and Grosskopf [8] considered Seiford and Zhu [23] and suggested an alternative approach based on the directional distance function to increase good outputs and decrease undesirable outputs. Korhonen and Luptacik [14] used DEA to measure the eco-efficiency of 24 coal-fired power plants in presence of bad outputs. Jahanshahloo et al. [15] presented an approach to treat both undesirable inputs and outputs simultaneously in non-radial DEA models. Kordrostami and Amirteimoori [16] considered the efficiency evaluation of a set of interdependent decision making sub-units (DMSU) which form a larger DMU with desirable and undesirable factors. Amirteimoori et al. [2] developed a DEA model which could be used to improve the relative performance via increasing undesirable inputs and decreasing undesirable outputs. Liang et al. [19] proposed an effective approach to deal with undesirable outputs and simultaneously reduce the dimensionality of data set.

Most recently, Lozano et al. [21], Akther et al. [1], Wu et al. [28], Hwang et al. [12], Wang et al. [27] and several researchers developed DEA models to measure the efficiency in such production systems.

Taking previous studies into account, this paper aims to develop a general model for efficiency evaluation of serial two-stage networks. To this goal, we reviewed several DEA based studies on efficiency evaluation of two-stage processes and measuring the performance of production systems in presence of bad outputs, briefly. Next, we develop a general network DEA model, which measures the efficiency of two-stage processes in presence of desirable and undesirable outputs. We will use an empirical data set of a poultry chain in order to illustrate the applicability of the proposed approach.

2 Incorporating undesirable outputs in DEA

There are many two-stage network processes in which some outputs from the first stage do not become inputs to the second stage, and the second stage has its own inputs. In addition, each stage may produce undesirable outputs. This study aims to propose a DEA based approach for measuring the efficiency of these types of problems.

Suppose that there are a set of n two-stage DMUs denoted by DMU_j $(j = 1, 2, ..., n)$ and each DMU_j has m inputs denoted by x_{ij} $(i = 1, 2, , m)$ to the whole process. Parts of these m inputs (I_1) are the inputs to the first stage $x^{(1)}_{i_1 j}$ $(i_1 = 1, ..., m_1)$, while the others (I_2) are used as inputs of the second stage $x^{(2)}_{i_2 j}$ $(i_2 = 1, ..., m_2)$. Suppose also that each DMU_j $(j = 1, 2, ..., n)$ has k outputs from its first stage, which then become inputs to the second stage z_{kj} $(k = 1, 2, ..., K)$ and are referred to as intermediate measures. We denote the outputs of the first stage as $y^{(1)}_{r_1 j}$ $(r_1 = 1, 2, ..., s_1)$. The outputs from the second stage are classified to desirable (good) outputs $y^{2g}_{r_2 j}$ $(r_2 = 1, 2, ..., s_2)$ and undesirable (bad) outputs $y^{2b}_{r_3 j}(r_3 = 1, 2, ..., s_3)$. Figure 2 illustrates such a described general two-stage network structure. Measuring a sub DMU's efficiency is straightforward. Each sub DMU is benchmarked with other sub DMUs in the same layer set operating in the same time period. Formally, the overall efficiency of each DMU can be measured by the following model:

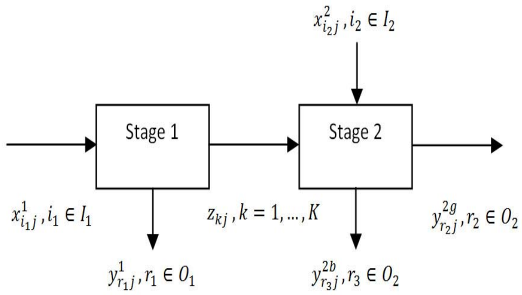

Figure 2: The general two stage network structure.

$$\begin{aligned}
&min \quad \tfrac{1}{2}[\tfrac{1}{s_1+m_1}(\textstyle\sum_{i_1=1}^{m_1}\theta_{i_1} + \sum_{r_1=1}^{s_1}\varphi_{r_1}) \\
&+\tfrac{1}{m_2}\textstyle\sum_{i_2=1}^{m_2}\theta_{i_2} \\
&subject\ to: \\
&\textstyle\sum_{j=1}^{n}\lambda_j x^{(1)}_{i_1 j} \leq \theta_{i_1} x^{(1)}_{i_1 o}, (i_1 = 1, 2, ..., m_1) \\
&\textstyle\sum_{j=1}^{n}\lambda_j y^{(1)}_{r_1 j} = \varphi_{r_1} y^{(1)}_{r_1 o}, (r_1 = 1, 2, ..., s_1) \\
&\textstyle\sum_{j=1}^{n}\lambda_j z^{(1)}_{kj} + s = z_{ko}, (k = 1, 2, ..., K) \\
&\textstyle\sum_{j=1}^{n}\mu_j x^{(2)}_{i_2 j} \leq \theta_{i_2} x^{(2)}_{i_2 o}, (i_2 = 1, 2, ..., m_2) \\
&\textstyle\sum_{j=1}^{n}\mu_j y^{(2g)}_{r_2 j} \geq y^{(2g)}_{r_2 o}, (r_2 = 1, 2, ..., s_2) \\
&\textstyle\sum_{j=1}^{n}\mu_j y^{(2b)}_{r_3 j} = y^{(2b)}_{r_3 o}, (r_3 = 1, 2, ..., s_3) \\
&\lambda_j, \mu_j \geq 0 \ \ \& \ \ s\ is\ free\ in\ sign
\end{aligned} \tag{2.1}$$

The efficiency of each sub DMU can be measured by using the equations (2.2) and (2.3):

$$E_1 = \tfrac{1}{s_1+m_1}(\textstyle\sum_{i_1=1}^{m_1}\theta_{i_1} + \sum_{r_1=1}^{s_1}\varphi_{r_1}) \tag{2.2}$$

and

$$E_2 = \tfrac{1}{m_2}(\textstyle\sum_{i_2=1}^{m_2}\theta_{i_2}) \tag{2.3}$$

As in the conventional DEA models, some efficiency scores obtained for stages 1 and 2 can increase depended on how an inefficient unit improves its performance. To derive the DEA frontier for two-stage processes (frontier projection) determines this improvement.

3 Empirical Example

The aim of this paper is to apply a network DEA model for measuring the efficiency of a set of poultry farms where in addition to the desirable outputs (Chickens, Feed Conversion Ratio, Produced Meat), the process produces some undesirable outputs (Mortality and Condemn). DEA studies about poultry efficiency measurement consider a DMU (farm) as a single process, while the process essentially could be split up into two or more main sub processes. According to new researches, such as Gous [11], the first 7 or 21 days of broiler production named as the golden time. For conducting a network DEA approach to the poultry farms, two sub-processes could be distinguished: one is related to the first 21 days of the broiler production and the other is the remaining time of the production period. The distinction between these two sub-processes has already been considered in the literature. In this Section, a real data set (consisted of 13 farms of Green Hen poultry which are located in Guilan Province, Iran) is used to illustrate the proposed approach. Each farm employs new born chicks, feed and other inputs to produce maximum meat while attempts to minimize consumed inputs and undesirable factors. The proposed two-stage model is illustrated in Figure 3. As an empirical example, Table 1 illustrates

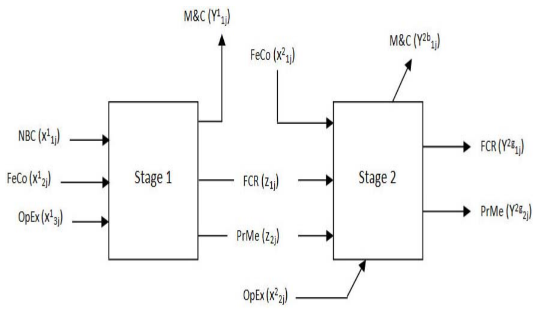

Figure 3: Poultry farm as a two-stage system (Note: Stage 1 includes first 21 days and stage 2 includes an interval from 22th day to the end).

a data set for 13 poultry farms (DMUs), where New Born Chicks (X^1_{1j}), Feed Cost (X^1_{2j}) and Operational Expenses (X^1_{3j}) are three inputs to the first stage, Feed Conversion Ratio (Z_{1j}) and produced Meat (Z_{2j}) are two intermediate measures, i.e. the outputs of the first stage and the inputs to the second stage, Mortality and Condemn (Y^{1b}_{1j}) is undesirable output of the first stage which leaves the system, Feed Cost (X^2_{1j}) and Operational Expenses (X^2_{2j}) are two external inputs to the second stage and Feed Conversion Raito (Y^{2g}_{1j}), Produced Meat (Y^{2g}_{2j}) and Mortality and Condemn (Y^{2b}_{1j}) are two desirable (good) and one undesirable (bad) output from the second stage, respectively.

The input/output values of each DMU (farm), the overall efficiency of the whole process (column 15) and the efficiency scores of the first and second stages (column 13 and 14) are presented in Table 1.

Table 1: Collected data from13 farms of Green Hen Poultry

height	Stage 1						Stage 2							
DMU	Input			Output	Intermediate		Input		Output			eff. 1	eff. 2	Eff
	NBC	FeCo	OpEx	M&C	FCR	PrMe	FeCo	OpEx	FCR	PrMe	M&C			
1	12700	148500	57370	467	1.69	6691.5	438500	97920	1.98	28582.2	173	0.9480	0.9905	0.9692
2	14670	171740	63900	513	1.65	7871.3	491760	110160	1.93	32387.2	197	0.9421	1.0000	0.9710
3	13300	154930	63220	1263	1.72	6921.3	435410	106150	2.00	28506.3	306	0.7974	1.0000	0.8987
4	15000	182880	66590	421	1.71	8280.9	518560	126650	1.95	34075.0	79	1.0000	1.0000	1.0000
5	12000	147490	57030	758	1.68	6340.5	415130	100700	1.98	26256.5	256	0.8495	1.0000	0.9248
6	14000	165080	63640	1098	1.70	7134.8	449710	113700	1.97	29828.0	263	0.7962	0.9721	0.8841
7	13000	168930	62020	646	1.75	7202.4	468450	110550	2.03	30158.7	144	0.8902	0.9513	0.9207
8	14900	175430	71680	821	1.62	7475.9	532190	119100	2.04	33414.6	214	0.7956	1.0000	0.8978
9	13500	169520	62300	518	1.71	7399.7	480800	106770	1.94	30439.0	246	0.9282	0.9872	0.9577
10	12800	144130	60930	623	1.63	6356.4	433090	105240	2.03	28223.5	167	0.8480	1.0000	0.9240
11	19800	235970	80960	1042	1.67	10373.2	685800	144430	2.01	44581.2	336	1.0000	1.0000	1.0000
12	11000	133540	51340	385	1.68	5933.8	378100	86880	2.00	25683.4	89	1.0000	1.0000	1.0000
13	12600	148870	57210	479	1.63	6521.1	440730	102420	1.88	28405.3	186	0.9075	0.9880	0.9478

Table 1 describes the relative efficiency scores from a Russell's extended method for 13 DMUs. From the efficiency results in Table 1, we notice that DMUs 4, 11 and 12 are overall efficient while DMUs 1, 2, 3, 5, 6, 7, 8, 9, 10 and 13 are inefficient. The inefficiencies of DMUs 2, 3, 5, 8 and 10 root in stage one, while DMUs 1, 6, 7, 9 and 13 are inefficient in both stages.

Based on the concept of target setting for inputs and outputs, inefficient DMUs can be made more efficient by projection onto the efficient frontier through proportional reduction of inputs or proportional augmentation of outputs. The projection of an inefficient DMU shifts it onto the efficiency frontier, thus the projected point can be regarded as a target point. The efficient frontier and DEA projections are provided in Table 2. The projection points indicate that DMU_2 needs to change its first stage inputs (New Born Chicks, Feed Cost and Operational Expenses) to 14272, 173969 and 63492 and reduce its undesirable output to 405, while other outputs (intermediates) of this stage, the external inputs and outputs of the second stage, remain fixed. The DMUs 3, 5, 8 and 10 have a similar condition and should follow the same policy if they are to be efficient. From Table 1, one sees that the overall efficiency scores of

Table 2: Projection matrix for 13 farms of Green Hen Poultry

height DMU	Stage 1						Stage 2				
	Input			Output	Intermediate		Input		Output		
	NBC	**FeCo**	**OpEx**	**M&C**	**FCR**	**PrMe**	**FeCo**	**OpEx**	**FCR**	**PrMe**	**M&C**
1	12280	149357	56103	393	1.67	6691.5	428580	98271	1.98	28582.2	173
2	14272	173969	63492	405	1.65	7871.3	491760	110160	1.93	32387.2	197
3	12698	154449	57974	405	1.72	6921.3	435410	106150	2.00	28506.3	306
4	15000	182880	66590	421	1.71	8280.9	518560	126650	1.95	34075.0	79
5	11690	142061	53941	390	1.68	6340.5	415130	100700	1.98	26256.5	256
6	13038	158700	59017	401	1.68	7134.8	453635	106363	1.97	29828.0	263
7	13177	160355	59797	409	1.72	7202.4	453671	103270	2.03	30259.7	144
8	13584	165520	60724	394	1.62	7475.9	532190	119100	2.04	33414.6	214
9	13478	164154	60573	401	1.66	7399.7	464333	107699	1.94	30494.2	246
10	11690	142112	53644	381	1.63	6356.4	433090	105240	2.03	28223.5	167
11	19800	235970	80960	1042	1.67	10373.2	685800	144430	2,01	44581.2	336
12	11000	133540	51340	385	1.68	5933.8	378100	86880	2.00	25683.4	89
13	11919	145074	53979	367	1.54	6521.0	433880	101554	1.88	28405.3	186

DMUs 1, 6, 7, 9 and 13 are 0.9692, 0.8841, 0.9207, 0.9577 and 0.9478, because of their simultaneous inefficiency in stage 1 and 2. The projection matrix suggests an input and output plan to reach to efficient score 1.0000, although in reality this may be hard to achieve. The projection of DMU_1 onto the efficient frontier would land at the point in which its first stage inputs (New Born Chicks, Feed Cost and Operational Expenses) and undesirable output are 12280, 149357, 56102 and 393, respectively; while its first intermediates measure is 1.67. To lie on the efficient frontier in the second stage, DMU_1 needs to reduce its inputs to 428580 and 98271, while the values of its outputs are estimated to be as their prior amounts. Evidences from projection matrix indicate that to relay on the efficient frontier, DMU_6 needs to reduce the first stage inputs and output to 13038, 158700, 59017 and 401. The first intermediate measure of DMU_6 should reduce to 1.68, while it experiences a decrease in its second stage's external inputs to 453635 and 106363. The DMUs 7, 9 and 13 have a similar condition and should follow the same policy. Obviously, for the three efficient DMUs, the projections would be coincided onto themselves.

4 Conclusion

The real life production and operation systems usually composed of two or more processes connected in series and produce undesirable outputs, in addition to desirable ones. In view of these facts, this study establishes a two-stage DEA model for measuring the efficiency of general two stage systems. This model involves the direct inputs and outputs for each stage and the intermediate flows between the two stages. An empirical case study of poultry farms in Guilan, Iran is discussed to illustrate effectiveness of the proposed approach. Results show that three DMUs (4, 11 and 12) are DEA efficient, while the others recognized as inefficient. A projection matrix is used to map inefficient units on efficient frontier, with change in their inputs and outputs values.

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Alireza Amirteimoori is an associate professor in applied mathematics operations research group in Islamic Azad University in Iran. He completed his Ph. D degree in Islamic Azad University in Tehran, Iran. His research interests lie in the broad area of performance management with special emphasis on the quantitative methods of performance measurement, and especially those based on the broad set of methods known as Data Envelopment Analysis, (DEA). Amirteimoori's

papers appear in journals such as Applied mathematics and computation, Journal of the operations research society of Japan, Journal of Applied mathematics, RAIRO-Operations research, International journal of advanced manufacturing technology, International Journal of Production Economics, Optimization, Expert Systems with Applications, Central European Journal of Operational Research, International Journal of Mathematics in Operational Research, Decision Support Systems, Journal of Global Optimization and etc.

Abbas Toloeie Eshlaghi is a professor of industrial management at the department of Management and Economic at Islamic Azad University, Science Research Branch, Tehran, Iran. He has published more than more than hundred papers. He translated more than ten books.

Mehdi Homayoonfar is a faculty member of Islamic Azad University, Rasht Branch, Rasht, Iran. He also is a PHD candidate of industrial management (Operation Research) in Science and Research Branch of Islamic Azad University. His research interests include: Multi Criteria Decision Making (Analysis), Statistical Analysis, Heuristic Approaches, Mathematical Modeling, System Dynamics and Strategic issues. He has numerous publications in the various Scopus and Elsevier journals and conferences.