Efficiency Evaluation of Wheat Farming: A Network Data Envelopment Analysis Approach

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Abstract

Traditional data envelopment analysis (DEA) models deal with measurement of relative efficiency of decision making units (DMUs) in which multiple-inputs are consumed to produce multiple-outputs. One of the drawbacks of these models is neglecting internal processes of each system, which may have intermediate products and/or independent inputs and/or outputs. In this paper, some methods which are usable for network systems are briefly reviewed. A new unified model is also introduced which can be easily applied for performance measurement of all types of network production process. As an example, for the application of network DEA models, performance evaluation of wheat production in Iran provinces is considered and the results are compared.
Keywords: Data Envelopment Analysis, Network DEA, Efficiency, Wheat production.

1. Introduction

Nutrition has become one of the most important subjects related with health and economic issues. Evaluating agricultural efficiency in different countries and areas and for different crops has strong practical implications and will help governments to meet the demands of the society. Wheat is one of the world's largest cereal grain crops with approximately 674.9 million tons produced in 2012.In human food, wheat is the main source of vegetable protein and it contains higher protein amounts in comparison with other major cereals such as maize or rice. Also along with rice, wheat is considered as the world's most favored staple food. So, it is necessary to evaluate wheat production as one of the most important ingredients of human food.

Decision making units (DMUs) such as wheat producers are the entities which consume some inputs to produce some output sand whose efficiencies should be evaluated. Efficiency of each DMU can be assessed by estimating the production frontier which shows the maximum possible production level of one commodity for any given production level of the other, given the existing level of production factors. Application of frontier analysis in efficiency measurement can be categorized into two groups with regard to how the frontier is specified; the parametric, the stochastic frontier function or the nonparametric, linear programming (LP) approaches. In parametric approach a specific production function is assumed to determine the production frontier and the relation between inputs and outputs. In nonparametric approach, there is no assumption for production function and the production frontier is derived by observed inputs and outputs. Nonparametric approaches have fewer assumptions than parametric ones, so, it makes them more applicable. As a pioneer, Farrell (1957), applied a nonparametric approach to evaluate the efficiency score of systems. Charnes et al. (1978), generalize Farrell's approach and present a new concept which is named data envelopment analysis (DEA).

Data envelopment analysis (DEA) is a nonparametric, mathematical programming approach for evaluating the relative efficiency of a set of decision making units (DMUs) that convert multiple inputs to multiple outputs. Classical DEA models deal with the DMU as a whole system and only consider the inputs consumed and the outputs produced by the system. So, they are not applicable for the systems composed of several processes because of ignoring the internal operations of the components. So, network DEA is presented to handle systems with more than one process. For example, although a network DMU is indeed inefficient, classical DEA models may determine it as efficient one. Generally, the achieved efficiency score of the classical DEA models

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(2009,a) and Kao (2009,b), respectively. The series structure is the one in the outputs of each process are consumed as the inputs of the next process and these products are introduced as intermediate products. In parallel structure, the production system is composed of some processes with their own inputs and outputs in which the sum of the *i*th input for all processes is equal to the *i*th input of the production system and the sum of the *r*th output for all processes is equal to the *r*th output of the production system. Although the mentioned structures are applicable for some production systems, there are many network systems which are not included in these structures and have more complicated structures. Therefore, series and parallel structure are not suitable for them. Next part is devoted to reviewing two network DEA models which can be exploited not only for series and parallel systems but also for some systems without simple structure of series and parallel.

2.1. Relational model

Consider a network system as depicted in Fig. 1, which does not have series or parallel structure. In this system, x_i^p is the i*th* input which is consumed in p*th* process, y_r shows output of the r*th* process which is divided into y_r^O and y_r^I,and they are the output of system and the input of third process, respectively.

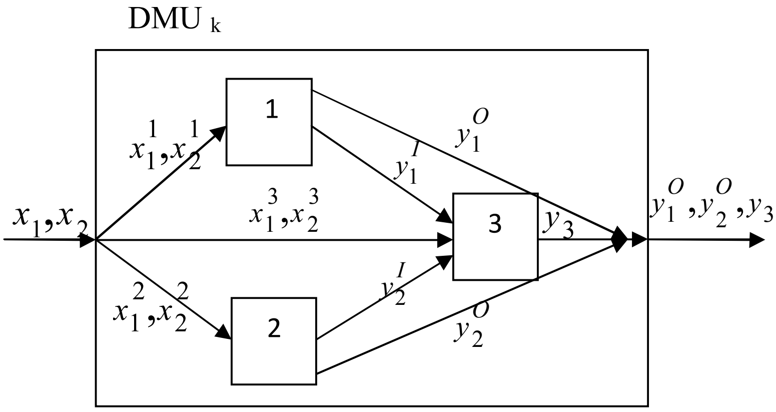

Fig. 1. Network structure

Kao (2009a) presented the following model to evaluate the performance of *n* network systems with the structure of Fig. 1.

$$
\begin{aligned}
&\theta_k = \max\ u_1 y_{1k}^O + u_2 y_{2k}^O + u_3 y_{3k} \\
&s.t \quad v_1 x_{1k} + v_2 x_{2k} = 1 \\
&u_1 y_{1j} - (v_1 x_{1j}^1 + v_2 x_{2j}^1) \le 0,\ j = 1,\dots,n \\
&u_2 y_{2j} - (v_1 x_{1j}^2 + v_2 x_{2j}^2) \le 0,\ j = 1,\dots,n \\
&u_3 y_{3j} - (v_1 x_{1j}^3 + v_2 x_{2j}^3 + u_1 y_{1j}^I + u_2 y_{2j}^I) \le 0, \\
&j = 1,\dots,n \\
&u_1, u_2, u_3, v_1, v_2 \ge 0 \qquad (2)
\end{aligned}
$$

2.2. Lozano's model

Lozano (2011) introduced model (3) to evaluate the performance of the network production systems (not necessarily series or parallel structure). In the following model, $P_I(i)$ is the set of processes, which consumes i*th* input, and, x_i^p is the i*th* input consumed in p*th* process and $x_{ik} = \sum_{p \in P_I(i)} x_{ik}^p$.$P_O(r)$ is the set of processes, which produces rth output, and, y_r^p is the r*th* output produced in p*th* process and $y_{rk} = \sum_{p \in P_O(r)} y_{rk}^p$. Let $P^{out}(d)$ and $P^{in}(d)$ be the set of processes, which produces d*th* intermediate product and consumes d*th* intermediate product, respectively. $z_d^p, p \in P^{out}(d)$ is the d*th* intermediate product produced in p*th* process, and $z_d^p, p \in P^{in}(d)$ is the d*th* intermediate product consumed in p*th* process.

weighted inputs based on outputs and inputs of under-evaluated process.

3. An Empirical Application

Almost one-third of Iran's total land is suitable for agriculture, but most of these areas are not under cultivation due to poor soil and lack of adequate water distribution. Therefore, only a small part of the suitable land is under cultivation. Some parts of the cultivated areas are irrigated and some parts of the cultivated areas are devoted to rainfed agriculture. Rainfed agriculture is usually performed in areas with adequate precipitation and natural water potential. In Iran, only the Caspian lowlands such as Gilan and Mazandaran receive extensive precipitation and can be considered for natural irrigation agriculture. Winter rains are adequate for growing grains in most of the areas among Azerbaijan, Khorasan and Fars, so, there is no need for additional irrigation. Areas such as the plateaus of central Iran, eastern and south eastern of Iran like Yazd and Hormozganare arid. Therefore, rainfed farming cannot be handled in these areas and irrigation can be considered as a choice for farming.

Wheat is considered as one of the main primary food of Iranians and the most important agricultural commodities in Iran in terms of production and consumption. Producing wheat is very important in terms of income, nutrition and employment of people. When it comes to consumption, the per capita consumption for bread wheat in Iran is about 160 kilogram which is higher than most of the other countries. Great demand for wheat in Iran and the difficulties to meet the demand pushed the government to import wheat. So, Iran is one of the largest wheat importers in the world.

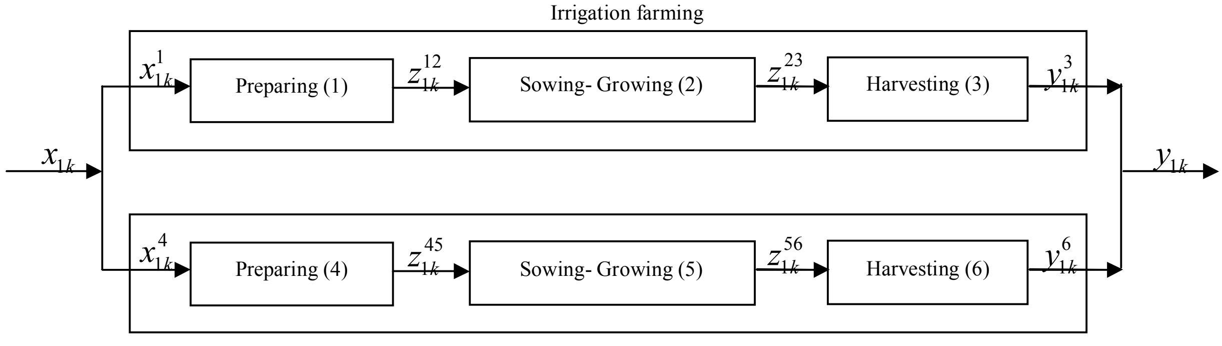

Fig. 2. Network structure of provinces

Iran governments encourage farmers to produce more wheat and they have developed some programs to increase wheat production. Presently, wheat is grown in many areas of Iran under irrigation and/or rainfed farming.

This section analyzes wheat farming efficiency in provinces of Iran in 2008-2009 crop year, starting on 22 September 2008 and ending on 22 September 2009. In this time period, Iran was composed of 30 provinces which were managed by the government. To evaluate the performance of 12 provinces in wheat production more accurately, we apply model (4) and the network structure as depicted in Fig. 2 the obtained results are compared with the ones of models (3) and (1). Fig. 2 is a network system with six processes, represented by two parallel processes where each process in the parallel structure is composed of three processes in series structure. The two parallel processes are irrigation farming and rainfed farming and the three series processes in each parallel process are preparing, sowing-growing and harvesting, respectively.

We present the system of Fig. 2 for Iran wheat farming with available data which were gathered by the Iranian Ministry of Agricultural Jihad (www.maj.ir). In the CCR model, x_{1k}, y_{1k} are only considered which are system's input and output, respectively.

Table 1 summarizes such descriptive statistics related to data set of 12 studied provinces regarding Iran wheat farming in 2008-2009 crop years. In preparing process, suitable land for wheat production is prepared with ploughing, clods crushing and manuring. Manuring is done in two parts, first in preparing step and second in growing step. In the preparation step, all the phosphate fertilizer and half of the nitrogen fertilizer are used. The input of the system, which is the aggregated input of the first and fourth processes, is consumed fertilizer (based on kilogram).

There is one intermediate product in the system which is the output of preparing process as well as the input of sowing-growing process and the output of the sowing-growing process as well as the input of the harvesting process. The intermediate product is land (based on hectare). The intermediate product (land) which is

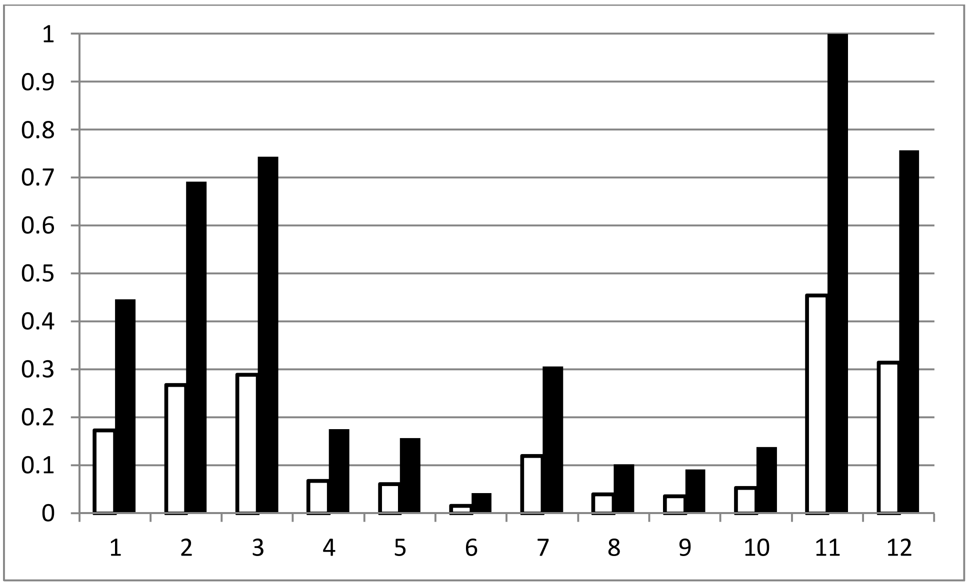

Fig. 3. General and CCR efficiency score of wheat production in 12 provinces of Iran, 2008-2009 crop year

The hollow and solid columns in column Fig 3 show the efficiency score of 12 provinces of Iran in 2008-2009 crop year which are obtained by the general model and the CCR model, respectively. In this chart, the horizontal and vertical axis represent the provinces and their efficiency score, respectively.

As it can be seen by solid columns, six provinces have the efficiency score more than 0.3 while the number of the provinces with this range of efficiency score which are achieved by general model is 2. In this chart, we see that the ranking of provinces based on their CCR efficiency score is the same as their ranking based on their general efficiency score. But this case is not held for all systems with network structures, and ranking obtained by CCR model for a particular unit is not essentially equal to the obtained ranking of the general model for the unit.

4. Conclusion

The conventional DEA models cannot be applied for production systems with network structure. They do not evaluate the performance of network systems accurately as they disregard the internal operations of the network systems. In this article, some common approaches handling network systems are introduced and analyzed based on their usage. These approaches are not applicable for all the network systems and they contain some drawbacks which restrict them. To overcome the problems of other approaches, the general model is introduced. Finally, the general network model is applied to assess the performance of wheat production. To this end, twelve provinces of Iran are considered as production units with complex network structure and the obtained results are compared with classical DEA approach and another network DEA approach to show the superiority of the general model.

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