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Measuring technical efficiency of potato production in Iran using robust data envelopment analysis

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ABSTRACT

A non-parametric method of data envelopment analysis (DEA) was applied to analyze the technical and scale efficiency of potato production in 23 Iranian provinces. In many real applications, inputs and outputs may be imprecise. In the present study, a robust DEA (RDEA) optimization framework was used to concentrate on DEA with uncertain data. The method was based on six inputs (human labor rent, land rent, diesel and machinery rent, irrigation water cost, fertilizer cost, pesticide cost) and the single output of potato gross return. The proposed DEA for 23 Iranian potato-producing provinces reveals that the average technical efficiency is 90% and scale efficiency is 97%. This suggests that inefficient provinces can potentially reduce their overall costs for potato production. A Monte Carlo simulation was used to compute the conformity of the rankings from the RDEA model with reality to illustrate the importance of varying the level of efficiency for different levels of conservatism.

1. Introduction

Potatoes are common human staples. They are grown in over 100 countries and are one of the most popular agricultural crops. Although this crop is fairly adaptable and can be grown in many regions, it requires care at all stages of growth and harvest. Since potatoes play a key role in the food security of Iranian households, recent governmental economic policies have increased attention on these agricultural products [1].

Increasing agricultural productivity is a long term policy objective in most countries. Achieving growth of productivity requires technological innovation, the more efficient use of production technologies or a combination of both [2]. Efficiency in production is a way to ensure that products are produced in the best and most profitable manner.

Several techniques can be used to evaluate decision-making units (DMUs) with a restricted multiplier. Data envelopment analysis (DEA) is a non-parametric mathematical programming technique in which multiple inputs and outputs are used to measure the relative efficiencies of DMUs [3,4]. The original DEA model was proposed by Charnes et al. [5]. Researchers have used DEA for crop production [6,7]. Mousavi-Avval et al. [8] employed DEA to analyze the efficiency of apple producers in Tehran province in Iran. There are many references regarding energy input and output rates for various agricultural crops in Iran [9–11]. Mousavi-Avval et al. [12] investigated the effect of optimization of energy to improve input costs and energy indices for soybean production.

Although DEA is a powerful tool to measure efficiency, some restrictions must be considered. One important restriction involves the sensitivity of DEA to the specific data under

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analysis. Most previous studies have assumed that input and output data do not deviate. This is rarely the case in real-life problems because much of the input and output data can be imprecise or vague and, as such, contribute to error.

In recent years, fuzzy set theory has been proposed as a way to quantify imprecise and vague data [13–15]. DEA has been combined with fuzzy scoring to identify both optimistic and pessimistic sets of efficient solutions [16]. Houshyar et al. [17] employed fuzzy modeling and DEA to evaluate the sustainability and efficiency of corn production with regard to energy consumption in Fars province in southwest Iran. In their method, some of the information on uncertainty and the distribution function of coefficients are ignored.

Fuzzy linear programming requires a method that ranks fuzzy sets, but using different fuzzy ranking methods may produce different results [18]. Efforts to mix a non-parametric method with stochastic variation in which multiple inputs and outputs have been biased by parametric assumptions about the distributional form of stochastic data required by the model [19,20]. Recent techniques generate the best approximations for a given underlying distribution of random parameters [21–24].

Skevas et al. [25] applied a DEA risk-adjusted efficiency approach to evaluate the efficiency of Dutch arable farming. The random data were assumed to follow a normal distribution. This choice pertains to simplifications provided from a computational stance and is not well suited to real life problems. Interval DEA (IDEA) is another approach to deal with uncertainty that was first proposed by Cooper et al. [26]. Karimi et al. [27] applied IDEA to analyze the efficiency of wheat production in eight Iranian provinces. The results showed that Fars province had the most and Kurdistan province had the least technical efficiency of the eight provinces. One difficulty to IDEA is the evaluation of the lower and upper bounds of the relative efficiencies of the DMUs.

One way to deal with uncertainty is to conduct an efficiency analysis of DMUs that is robust and can identify imprecise data changes. A more recent approach is robust optimization, which computes feasible solutions for a range of scenarios with uncertain parameters and optimizes an objective function in a controlled and balanced manner in response to uncertainty in the parameters [28]. Robust DEA (RDEA) is a non-linear programming technique to measure efficiency that deals with data uncertainty uses the interval approach [29]. This method is based on the robust optimization proposed by Bertsimas et al. [27] and Ben-Tal and Nemirovski [30,31].

The present study applied DEA to benchmarks and ranked the technical efficiency of potato production in 23 Iranian provinces based on six important inputs (human labor cost, land rent, diesel and machinery rent, irrigation water cost, fertilizer cost, and pesticide cost) and the gross return for potatoes as the output. The potato was selected because of its unique position in the national economy. It generates employment and food security for the majority of Iranians. RDEA was used to account for uncertainty in the analysis. This method, unlike stochastic and fuzzy DEA, does not assume that uncertain parameters are random variables with known distributions. Unlike the interval approach, in RDEA, the relative efficiencies of the DMUs have no lower or upper bounds to complicate ranking of DMUs.

Section 2 provides the background of the mathematical details of the original DEA and the RDEA. Section 3 gives the definition and sources of the data used. The empirical results of the analysis are presented and discussed in Section 4. Section 5 concludes the paper.

2. Case study and data collection

This study utilized data selected from 23 potato-producing provinces of Iran. The data for planning year 2010–2011 were collected from the following agricultural planning units: district statistical yearbook of the Department of Regional Planning and Development, Jehad-e Keshavarzi Organization, and the Iranian Ministry of Energy [32–34]. The required data is listed in Table 1 and clearly shows the variation between input cost and output return for each DMU. For example, land rent is \$2802 per ha in Fars and \$439 per ha in Semnan. This variation in input level suggests poor resource management by producers at some levels. This variation highlights the potential for improvement of economic efficiency in potato-producing provinces of Iran.

3. DEA and RDEA models

3.1. *Charnes–Cooper–Rhodes model*

In the Charnes–Cooper–Rhodes (CCR) model, the efficiency of an evaluated entity is the ratio of its weighted output to its weighted input where the ratio for each entity is not greater than 1. Assume that there are n DMUs, m inputs, and s outputs. Suppose x_{ij} $(i = 1, \ldots, m,\ j = 1, \ldots, n)$ is the quantity of input i consumed by DMU_j and y_{rj} $(r = 1, \ldots, s,\ j = 1, \ldots, n)$ is the quantity of output r produced by DMU_j. The original CCR model measured efficiency of DMU_o where index o is the DMU evaluated as follows (technical efficiency) [5]:

$$\begin{aligned} \max \quad & \theta_o = \sum_{r=1}^{s} u_r y_{ro}, \\ \text{subject to} \quad & \sum_{i=1}^{m} v_i x_{io} = 1, \\ & \textstyle\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leqslant 0, \quad \forall j, \\ & u_r, v_i \geqslant 0 \qquad \forall r, i. \end{aligned} \tag{1}$$

where θ_o is obtained using superior inputs and outputs of DMU_o by maximizing the objective function in Eq. (1) with respect to the weight variables. Using the first two constraints in Eq. (1), the θ_o of DMU_o is (0, 1). Adding w to $(\sum_{r=1}^{s} u_r y_{ro} + w)$ and constraint $(\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} + w \leqslant 0)$ of Eq. (1) relaxes the CRS restriction and envelopes the data more closely than does CRS technology. Technical efficiency is a relative measure of efficiency under a less restrictive variable for returns to scale technology by the addition of variable w. This model is known as the BCC model [35].

3.2. *Interval DEA models*

This section introduces the basic concepts of a DEA model with imprecise data. For interval DEA models, assume that all input and output data cannot be exactly obtained because