Novel theory and methodology developments in data envelopment analysis

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The announcement of this special issue of the *Annals of Operations Research* coincided with the 100th Birthday of William W. Cooper, a co-founder of data envelopment analysis (DEA). It is dedicated to his memory.

The academic discipline of efficiency assessment of organizations using DEA has grown rapidly since the publication of the seminal papers co-authored by Charnes, Coper, and Rhodes in 1978, and by Banker, Charnes, and Cooper in 1984. More than 30 years on, the field of DEA is growing steadily, attracting unabated interest from the management science and economics communities, and continuing to be applied in practice to address new problems in policy making and management. New models and methods developed in recent years allow the assessment of the efficiency, performance, and productivity of organizations or decision making units (DMUs) under different assumptions about the production process, using different types of data, and for different assessment objectives and scenarios.

The papers contained in this issue contribute to the theory and methodology of DEA in several ways. The first four papers provide innovative characterizations of the properties of the DEA efficiency measure. The next four papers describe applications of the DEA approach to evaluate the performance of different service organizations. The last six papers focus on modelling and computational aspects of the DEA approach.

Krivonozhko, Førsund, and Lychev consider various approaches suggested in the DEA literature to expand the production frontier by introducing artificial, or unobserved, DMUs. The authors establish theoretical relationship between different concepts of artificial DMUs and show their impact on the production frontier. This development is further supported by computational experiments.

Banker, Chang, and Zheng investigate why the super-efficiency procedure in DEA fails to rank efficient DMUs satisfactorily and find that the problem originates with DMUs that have relatively small output and input values. They also document that the use of the super-efficiency procedure to detect outliers is more effective when the noise level is high.

The paper written by Färe, Grosskopf, Karagiannis, and Margaritis investigates the relationship between DEA models and some other known linear programs. This includes the standard diet problem and its dual, and the benefit-of-the-doubt formulations.

The contribution of Dougherty, Ambler, and Triantis goes beyond the conventional DEA methodology and views DMUs as agents in a management system modelled by the complex adaptive systems framework. This allows the authors to consider different aspects of the "flocking" behavior of DMUs and suggest various insights into their performance patterns.

The paper by Podinovski and Wan Rohaida demonstrates the use of the hybrid returns-to-scale DEA model in the assessment of efficiency of public universities in Malaysia. This model assumes that the inputs and outputs representing staff and students are fully scalable as in the constant returns-to-scale model, but that the funding levels and publications are not, and so are modelled by a variable returns-to-scale assumption.

Fukuyama and Weber suggest a two-stage network DEA model for assessing the efficiency of Japanese banks. In this approach, the first stage produces deposits that are subsequently used as inputs in the second stage to produce a portfolio of loans and investments. The authors further estimate the corresponding dynamic network Luenberger productivity index based on several years of available data on banks' performances.

Simper, Hall, Liu, Zelenyuk, and Zhou consider the assessment of efficiency of South Korean banks using the profit-based modelling approach. The focus of this paper is on the investigation of the relationship between the choice of three different risk management variables and the resulting efficiency ratings of the banks.

Miller, Wang, Zhu, Chen, and Hockenberry use a novel DEA approach to assess the impact of a health care reform on hospital performance. The authors introduce an integer-valued non-radial Russell DEA model to assess the efficiency of hospitals simultaneously with respect to costs and quality of care. Although the suggested model is nonlinear, the authors show how it can be solved by methods of parametric integer linear programming.

The paper by Chen and Lai is devoted to the practical problem of solution of DEA models with a very large number of observations. The authors develop an algorithm that requires solving a number of small linear programs instead. A numerical experiment is presented to highlight potential computational savings of the proposed approach.

Mehdiloozad, Ahmadi, and Sahoo propose a new classification of DMUs based on combined notions of Pareto and Farrell efficiency. The authors prove that the type of DMU corresponding to the proposed classification can be established in a single stage, by solving a specially constructed linear program.

The paper by Mayston considers an extension of the DEA methodology to applications in which inputs representing resources available to a DMU depend on the quality of the resulting output. As argued in the paper, such relationships are common in the public sector applications, and these are not properly represented by the conventional notion of production

frontier. The author proposes a modified DEA approach that accounts for the above interdependency.

Cherchye, De Rock, and Hennebel extend a methodology in which certain proportions of joint inputs can be explicitly attributed to particular outputs. In this extension the authors introduce and explore a measure of coordination efficiency which reflects potential efficiency gains obtained from reallocation of such inputs across outputs.

The paper by Li, Liang, Avilés-Sacoto, Imanirad, Cook, and Zhu is concerned with the modelling of production processes in which every DMU may be regarded as consisting of several subunits, each consuming a share of the inputs and producing a share of the outputs. The efficiency of a DMU is then obtained as a weighted average of the efficiencies of the subunits. The authors consider an extension to this methodology in which different sets of inputs may produce the same output.

Hatami-Marbini, Agrell, Fukuyama, Gholami, and Khoshnevis contribute to the methodology of fuzzy DEA. Their paper is concerned with determining a small lower bound epsilon on the input and output weights that re-shape the weakly efficient part of the production frontier. The proposed approach is contrasted with the existing alternative methods, and a numerical example is used for illustration.

The Guest Co-Editors are indebted to all authors and reviewers whose hard work has contributed to this special issue.