Advances in Data Envelopment Analysis

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Since its introduction in 1978, Data Envelopment Analysis (DEA) has become one of the preeminent non-parametric methods for measuring efficiency and productivity of decision making units. Charnes, Cooper, and Rhodes (1978) provided the original DEA constant returns to scale (CRS) model, later extended to variable returns to scale (VRS) by Banker Charnes, and Cooper (1984). These 'standard' models are known by the acronyms CCR and BCC, respectively, and are now employed routinely in areas that range from assessment of public sectors, such as hospitals and health care systems, schools, and universities, to private sectors such as banks and financial institutions (Emrouznejad, et al, 2008, 2011). The main objective of this volume is to publish original studies that are beyond the two standard CCR and BCC models with both theoretical and practical applications using advanced models in Data Envelopment Analysis.

The volume opens with three papers on theory and applications of environmental and eco-efficiency. The first paper by *Luiza Badin, Cinzia Daraio and Léopold Simar* offers a state-of-the-art review of the literature that includes environmental variables in nonparametric and robust (to outliers) frontier models and to analyze and interpret the conditional efficiency scores, capturing their impact on the attainable set and/or on the distribution of the inefficiency scores. Authors argue that the performance of economic producers is often affected by external or environmental factors that, unlike the inputs and the outputs, are not under the control of the Decision Making Units (DMUs). These factors can be included in the model as exogenous variables and can help to explain the efficiency differentials, as well as improve the managerial policy of the evaluated units. This paper develops a procedure that allows one to make a local inference and provide confidence intervals for the impact of the external factors on the process. Authors advocate for the nonparametric conditional methodology, which avoids the restrictive "separability" assumption required by the two-stage approaches in order to provide meaningful results. An application with real data on mutual funds shows the usefulness of the proposed approach.

In the next paper, *Isabelle Piot-Lepetit* investigates how the directional distance function defined in a DEA type nonparametric framework provides a highly flexible

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structure for modelling producer behavior in the presence of polluting emissions and environmental regulations. This paper presents five models describing different "command and control" type policy measures with economic interpretations of nitrogen pollution in agricultural origin. These measures concern the management of the mandatory constraint on the spreading of organic manure and the investment in manure treatment facilities. The study also simulates the use of an economic instrument by enforcing the individual manure constraint at an aggregated level. Using individual and aggregated DEA models, this paper provides insights into the impact of individual and collective management of environmental policy instruments.

In another study on eco-efficiency, *Chien-Ming Chen* re-examines the unintended consequences of the two widely cited models for measuring environmental efficiency—the hyperbolic efficiency model (HEM) and directional distance function (DDF). The author highlights the existence of three main problems: (1) these two models are not monotonic in undesirable outputs (i.e., a firm's efficiency may increase when polluting more, and vice versa), (2) strongly dominated firms may appear efficient, and (3) some firms' environmental efficiency scores may be computed against strongly dominated DMUs. Using the supply-chain carbon emissions data from 50 major U.S. manufacturing companies, this study empirically compares these two models with a weighted additive DEA model. The empirical results corroborate the analytical findings that the DDF and HEM models can generate spurious efficiency estimates and must be used with extreme caution.

This volume continues with two papers on advanced network-DEA models. *Tsung-Sheng Chang, Kaoru Tone and Quanling Wei* highlight that all network DEA models proposed in the literature so far either implicitly or explicitly assume that all entities within the network (system) are owned by a single owner, i.e., a centralized system. As a result, those models are not applicable to performance evaluation for a wide variety of distributed and hybrid systems in practice. This study shows the importance of taking into account the ownership structure of networks (systems) in constructing effective network DEA models, and accordingly develops three ownership-specified (centralized, distributed and hybrid) network DEA models in terms of both input- and output-orientation.

The next paper on network-DEA assesses the efficiency of National Basketball Association (NBA) teams. *Plácido Moreno and Sebastián Lozano* use a Slacks-Based network-DEA model to evaluate the potential reduction of inputs consumed (team budget) and outputs produced (games won by the team) of NBA teams. The study considers the distribution of the budget between first-team players and the rest of the payroll. The proposed network DEA approach consists of five stages, which evaluate the performance of first-team and bench-team players, the offensive and defensive systems, and the ability to transform the points made by team and by the

opponents into wins. The results show that network DEA has more discriminating power and provides more insight than the conventional DEA approach.

The sixth paper provides an interactive classification using DEA. *Parag C. Pendharkar and Marvin D. Troutt* illustrate how DEA can be used to aid interactive classification. Authors assume that the scoring function for the classification problem is known. They use DEA to identify difficult-to-classify cases from a database and present them to the decision-maker one at a time. The decision-maker assigns a class to the presented case, and based on the decision-maker class assignment, a trade-off cutting plane is drawn using the scoring function and decision-maker's input. The procedure continues for a finite number of iterations and terminates with the final discriminant function. This study also shows how a hybrid DEA and mathematical programming approach can be used when user interaction is not desired. For the non-interactive case, it compares a hybrid DEA and mathematical programming based approach with several statistical and machine learning approaches, and shows that the hybrid approach provides competitive performance when compared to the other machine learning approaches.

The next paper is an investigation of total factor productivity growth and directions of technical change bias with evidences from OECD and non-OECD countries. *Po-Chi Chen and Ming-Miin Yu* use a Malmquist index and its decomposition of technical change and efficiency change by releasing the hypothesis of neutral technology to divide technology into the magnitude of the shift in the world production frontier and input-biased technology, and to show that in order to gain more benefit or to not lose so much benefit from technology change, it is important for countries to coordinate their choice of input mix with the directions of technology bias if their technical changes are biased. The results indicate that both OECD and non-OECD countries tend to show capital-using/labor-saving, capital-using/energy-saving and energy-using/labor-saving technical change bias over the entire period. The production pattern of a majority of countries is shown to have been able to take advantage of their technological innovations.

In the next study *Chih-Ching Yang* enhances a DEA model for decomposition of technical efficiency in banking. This paper modifies the directional distance function by simultaneously but disproportionately seeking the maximum expansion of each desirable output and contraction of each undesirable output for efficiency measurement, which allows one to decompose the technical efficiency (TE) into operating efficiency (OPE) and risk management efficiency (RME). The OPE characterizes the ability of a bank to expand the room for profits through its regular business activities, while the RME describes a bank's ability in risk management activities for sustaining operations. To illustrate the usefulness of the proposed model, a case study of Taiwan's domestic commercial banks is presented. The major findings are that operating inefficiency is the main source of technical inefficiency,

although banks with a higher OPE generally also have a higher RME. Banks subordinate to financial holding companies are more efficient in both OPE and RME than stand-alone banks.

Finally, *M. Khodabakhshi and K. Aryavash* offer a procedure for the fair allocation of common fixed cost or revenue using a DEA model on three principles: (1) allocation must be directly proportional to the elements (inputs and outputs) that are directly proportional to imposed common fixed cost or to obtained common fixed revenue. (2) allocation must be inversely proportional to the elements that are inversely proportional to common fixed cost or revenue. (3) the elements that have no effect on common fixed cost or revenue must have no effect on allocation as well. They show the usefulness of the proposed approach with an application of gas companies.

Overall, the papers included in this special volume give us a small but nevertheless fairly truthful snapshot of the current trends of research using advanced DEA models. All of these papers contribute either to the theoretical or implementation aspects of the field and should be of interest to a broad academic audience.

To conclude, we are grateful to all the authors and to the reviewers who made this special volume possible. Although it was not possible to accommodate all submitted manuscripts, the editor hopes that all authors found the feedback helpful for their future work. The guest editor thanks *Dr. Endre Boros*, Editor-in-Chief of the *Annals of Operations Research*, for giving us the opportunity to prepare this special volume.

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