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Joseph C. Paradi
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Data Envelopment Analysis in the Financial Services Industry

A guide for practitioners and analysts working in Operations Research using DEA

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A Guide for Practitioners and Analysts Working in Operations Research Using DEA

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To our significant others: Monika, Linda, and Bernice; David's supportive daughters Amanda and Caroline; and Joseph's sons Joseph and David and grandchildren Andrew, Laura, and Sophie

Foreword

I am extremely pleased that the authors have written this book and honored that they have invited me to develop the foreword.

I have known Joe Paradi and David Sherman for a number of years and have followed their pioneering research from the beginning. Joe was the first to utilize extensive data visualization to communicate DEA results to managers, while David wrote the first introductory monograph explaining DEA for the service sector. Both have extensive consulting experience and managerial expertise which produce a unique and valuable perspective. Over the years, they have developed separate impressive research agendas. I am very pleased that they have joined forces with Fai Keung Tam to produce this book. We have had many discussions of the critical need for such a book collecting together and showcasing studies of managerial importance. The result should help the reader better appreciate the power of DEA as a novel approach for organizing and analyzing data to produce valuable insight.

As mentioned in their introduction, there has been a host of DEA-related articles produced in the past 40 years. The DEA bibliography that I maintain now contains around 15,000 books, dissertations, and articles published since 1978. Unfortunately, the majority of these articles are not particularly useful. Many are a simple study of a specific industry in a single country at one point in time for which the results simply state the relative efficiency scores for a list of DMUs. Such articles are not valuable in that they are a simple ordering of units and do not provide helpful insight for managers such as trends, comparisons across regions, organizational subgroups or ownership types, multinational comparisons, etc. In short, the explanatory power is small frequently due to the shortage of temporal data, failure to perform a thorough analysis across multiple models, model extensions, and various subsets of the data and/or shortcomings of the experimental design.

This book seeks to address this problem by showcasing articles from the financial services area that describe innovative approaches and novel applications that provide insight and uncover transferable best practices. Of course the models, approaches, and advice while stated in the context of financial services are easily applicable to other industry sectors.

My hope is that DEA researchers will familiarize themselves with these compelling applications and approaches and heed the authors' guidance and advice. Hopefully this will result in a significant increase in the number of useful DEA articles for which rigorous analysis produces valuable insight and directly impacts managerial practice. Such an advancement will enhance the field and more fully realize the potential of the DEA methodology.

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Acknowledgments

Once a person writes a book, s/he learns the hard lesson that it takes several times more effort than anticipated, longer than planned and the completion almost becomes an obsession. Of course, aside from the authors of the book, a lot of others make contributions, some more, some less, but all are essential to success.

First, we would like to thank the owners of the copyrighted materials they so graciously allowed us to use and include in this book. All good contributions to science are based on the work that has been done by many others in the far as well as in the recent past.

Aside from the use of copyrighted materials from external sources, we made use of a substantial amount of research results and work completed or being worked on by our own students. These outstanding young women and men form the foundation of the future in not only DEA but all aspects of our society. We appreciate their enthusiasm in helping us with this book. They deserve much of the credit for the ideas, development, and progress in the application of DEA to real-life problems. Here they are and our postdoctoral fellows:

Burçu Anadol	Parisa H. Ardehali	Maryam Badrizadeh
Barak Edelstein	Allison Hewlitt	Angela Tran Kingyens
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Zijiang Yang		

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We also thank all who suggested ways to do things, provided examples of how to view real-world problems, and added the "reality" factor to the work we reported on. We thank dozens of professionals who collaborated with us in the work, without whom the underlying research and therefore this book could not have been completed. Among these stands out David Paradi who is a master at using PowerPoint and has contributed his knowledge and enthusiasm to the production of figures we present here, and many other technical issues.

A special thank you is due to Professor Joe Zhu who suggested to us that a book like this was needed and then answered all our questions. He is one of today’s most respected authors and authorities on DEA. Very much is owed to our late friend, Prof. W.W. (Bill) Cooper, who was one of the creators of DEA and was first to introduce us to the boundless problem-solving capabilities of this excellent tool.

And last, but not least, we thank our better halves Monika Paradi, Linda Sherman, and Bernice Cheng for their patience and even encouragements while they were neglected during the creation of this book.

Contents

List of Figures

List of Tables

Introduction

Data envelopment analysis was first titled with this name in the paper by Charnes, Cooper, and Rhodes in 1978. The initials DEA have since been widely adopted. The concept was previously exposed in Farrell's seminal paper (1957): "The measurement of productive efficiency." Farrell did not have the power of modern computing equipment at his disposal, so the development of practical applications was not feasible in a practical sense. But time passed and technology developed so that Farrell's work became possible to apply to complex problems with multiple inputs and outputs. Linear programming capabilities allowed the DEA models to be used for varied problems. Running DEA often required rerunning a linear program thousands of times, a capability that was not readily available in the 1950s. Today, running numerous linear programming iterations required for DEA can be done on the average personal computer by simply using DEA custom-coded programs or even Microsoft Excel.

Slowly, researchers in operational research and economics began to apply DEA to their problems. With few exceptions, their primary goal was to extend the theoretical foundations of the science and report this in traditional academic refereed journals in management science, economics, social science, and mathematics. As more researchers became involved in looking at DEA as a fruitful approach to management and economic problems and their works were published, the literature grew, at first slowly and in recent years quite rapidly. While in the early days it was possible to keep up with the new papers as they appeared (e.g., Seiford 1997; Emrouznejad et al. 2008), this is now essentially impossible as it would take a person working full time just to assemble the bibliography. The number of books alone now published is around 100 and growing. The DEA technology is now well established but still developing, and relatively small theoretical additions, extensions, and refinements continue to be reported in the academic literature. One of the best sources of the most up-to-date information on DEA is found at A. Emrouznejad's DEA Zone on the web (2017): www.deazone.com.

However, the major challenge and unfinished DEA work is, in our view, that only a small portion of the published works deal with applications of DEA to real-life problems and even fewer result in production systems making use of DEA. The reader might challenge this assertion, so let us clarify. While most recent papers used real data obtained from credible sources, such as the OECD, national statistics from agriculture to retirement homes, and the financial and economic data sources, studies based on such data do not enable managers to obtain directions on how to enact policy or improve practice in their businesses or other organizations. Even when there is the potential to apply the DEA findings to real operating organization datasets, the results of the analyses are published without pursuing the application to generate the potential benefits. While there are examples where the results have been applied and the positive and negative results are reported, these papers reflect an incredibly small fraction of the total DEA published literature. There are applications that have been successful that have not been published, and while we cannot know the universe of the works not published, discussions with academics and end users of DEA suggest that these unpublished applications are not likely to be very large in number. Two fields that stand out in these studies are health care and banking where hundreds of papers were written over the past couple of decades, but with very few being of practical use to the people who operate these institutions.

The early focus of DEA was applying it to units in any organization that have control over their activities, and where there is some manager that assesses performance of each unit and makes decisions about how the unit operates in an effort to improve its outcomes. The term adopted for these operating units was *decision-making units*, or DMUs. These initials, DMUs, are well understood by the DEA community, but this is not a term that is naturally found or used in business, government, or other organizations. The terminology in itself may be sufficiently arcane and unfamiliar to potential users that it may have contributed to the slow adoption of DEA. The current use of DEA continues to heavily focus on understanding and improving the performance of the defined DMUs, but has also broadened to recognize DEA's ability to identify relationships in complex operating data that offer new insights into the way organizations operate and other paths to manage performance (Sherman and Zhu 2013).

The definitions of what a DMU is determine the usability of the results. For economists, the aggregate data is useful when they advise governments on policy or evaluate the national or international health of certain sectors of interest. The DMU may be defined as a political unit, country, industry, etc. But useful direction for the managers of units such as bank branches, hospital departments, farms, retirement homes, etc. is seldom provided, yet this is where real operating benefits can be achieved. For example, when a study is conducted on the efficiency, productivity, or effectiveness of the banking industry, the outcomes for each bank (the DMUs in the models) offer no implementable findings as the data is aggregated and applies to the DMU as a whole. Of course, the outcome of such a study may well be useful for the regulator or government evaluation of the health of the industry and in identifying regulatory policies that would improve overall productivity. A concrete example of DEA being applied to help regulate an industry is the utilities sector, where it has been used to manage electricity producers in Europe and Brazil (Agrelle et al. 2005).

When the focus is on DMUs that are finite operating units such as bank branches, clinics, physicians, hospitals, nursing homes, and focused services in health care, DEA provides, in addition to an assessment of the DMUs, insights that can allow a manager to directly adjust methods of operations. These adjustments can provide the opportunity to measurably improve the performance of the DMUs analyzed with DEA.

This book is intended to address the challenge of how to apply the DEA technology to data, where the data is relevant and detailed enough to allow results to be useful to the managers by implementing the outcomes from the study to improve the performance of their organizations. In other words, we look at the practitioners' problem of applying improvements to the businesses or institutions where the benefits are directly received by the owners, employees, and/or customers of the firm. Of course, the entire firm benefits from the individual improvements. For example, an analysis of a retail chain store or franchising operation where managers do have the power to implement the improvements suggested by a DEA analysis could result in lower costs for individual operating units (the DMUs in this type of study), improving profitability of these units and thus an augmentation of the system-wide success and attractiveness of owning one of the franchised units.

Our intent and objective is to provide any reader of this book a set of useful approaches and techniques which they can apply and, if done as suggested in this volume, would enable the reader to improve their firm's performance (or that of their client firm if they are consulting for them). However, there are many sectors in a large economy and no single book can cover them all. Therefore, we restricted ourselves to the financial sector where there are a number of studies published examining the actual performance level of the firm and where the firm should go to reap the benefits of the study. Perhaps it would be appropriate to see this book as a *how-to* manual where the practitioner or analyst can find a study that relates to their problem, often directly, while other times they may find an example where there are similarities to their organization but which requires some adaptation to be effective.

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Part I
Data Envelopment Analysis, in Brief, with Little Math!

Introduction

In Part I of this book we provide an overview of DEA but without a lot of mathematics, except to allow the explanations to make sense. Our intent is to allow the reader to assess the technology and understand it well enough to delve into whatever details he or she feels necessary to their needs. This part also provides a brief survey and summary of some of the large body of published DEA studies on banking and other financial services.

Chapter 1
DEA Models Overview

We begin with the basic DEA Models and some useful extensions (although we expect that some will see it as too much while others as too little). While we promised to minimize the mathematics, some are, unfortunately, unavoidable. We have excluded any specific discussion of the underlying linear programming (LP) mathematics that drives DEA, and while some general understanding of this is helpful for understanding the academic literature, it is not needed to understand the benefits and ways to apply DEA.

The next issue here is how to select what are "inputs" and what are "outputs". One would assume that this is easy since whatever is used in the production model is an input and what is produced is the output. But there are some issues, such as undesirable outputs (e.g. bad loans) and inputs where we might want more (e.g. deposits in a bank branch). To make matters more confusing, some measures may well be used as inputs in some models while outputs in others – such as bank deposits. We also address some data issues in this part.

Model formation is another subject fraught with controversy and we point to some issues and suggest ways to address these problems.

Finally, we provide a brief history of DEA and its development and sketch out the DEA models family tree to show how things connect together from the Charnes et al. (1978) model to some of the more sophisticated models that have been developed since that seminal paper saw the light of day. Some of the milestone applications of DEA in the financial services are also provided.

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Basic DEA Models

Introduction

Data Envelopment Analysis (DEA) is an example of a frontier approach. Frontier approaches identify and assess the areas or examples of best performance or best practice within the sample, i.e. those located on the "frontier". The frontier identified by DEA suggests the best performance within the group of operating units being evaluated and does not promise or even suggest that these represent the theoretically best performance. These methods can be contrasted with regression techniques that seek to explain the average behavior within a sample. Frontier techniques can be divided into two types: parametric and non-parametric. Parametric techniques specify a frontier function to be fitted to the data, with or without accounting for noise in the data. DEA is a non-parametric approach, meaning that no prior functional form is assumed for the frontier, outside of a simple assumption of piecewise linear connections of units on the frontier. The ability to apply DEA without assuming a functional form is a very powerful characteristic. This means that the analysis can proceed without knowing the production function, which is the way inputs are transformed into outputs. Non-parametric approaches can simultaneously handle multiple inputs and outputs, but do not account for noise in the data, treating all deviations from the frontier as inefficiencies (Cummins and Zi 1998).

As an efficiency measurement and evaluation methodology, DEA is particularly useful in cases where sample units, termed decision making units (DMU), use multiple inputs and outputs, and are operating under comparable conditions. DEA primarily measures technical efficiency, i.e. focusing on levels of inputs relative to outputs, as opposed to economic efficiency which would also consider market prices. The use of levels of inputs and outputs is another powerful characteristic of DEA, in that it can incorporate inputs and outputs in the natural units in which they are measured and does not require them to be converted to the same units of measure – specifically, they are not required to be converted to monetary units.

DEA permits the evaluated DMUs to appear to be as good as possible, a feature that can be deemed as providing a "fair" evaluation of the DMUs in the sense that the analysis should limit objections amongst DMUs regarding their evaluations. This characteristic stems from the optimization underpinning of DEA, where DEA assigns the highest efficiency rating to each DMU compared with the set of DMUs being analyzed. It essentially gives the "benefit of the doubt" to each unit. From a management perspective, DEA will be less likely to erroneously identify an efficient unit as inefficient, and while it may not capture all inefficient units, the ones identified as inefficient will have real potential for improvement.

On the contrary, this same "fairness" can permit DMUs to select evaluation criteria that may be deemed as inappropriate or unrealistic. The DEA results, including the evaluation criteria, can be reviewed and adjusted by the user to rerun DEA to include more appropriate criteria. This is one of several ways DEA can be adapted to the specific operating environment of the DMUs. These