Preface

INTRODUCTION

As the editors of *Data Envelopment Analysis (DEA) Methods for Maximizing Efficiency*, we are thrilled to present a comprehensive and timely resource for researchers, practitioners, and students in science and engineering. This book fills a significant gap in the literature by addressing the application of DEA, a critical and evolving tool in measuring and enhancing technical efficiency, particularly in scientific and engineering contexts. Since its inception by Michael Farrell in 1957, DEA has primarily been applied in economic and management fields. However, its potential in science and engineering has remained largely untapped. This gap can be attributed to both a need for more relevant data in these fields and a limited understanding of how DEA can be effectively applied to assess and improve decision-making processes. Recognizing this, our book embarks on an interdisciplinary journey, showcasing how DEA can be a vital instrument for performance measurement and improvement in various technical domains. It delves into the practicalities and complexities of applying DEA in scientific and engineering disciplines, which involve highly technical processes and decision-making units (DMUs). A total of 31 authors from 12 countries contributed a total of 14 chapters. A total of 19 chapters were submitted, and following a double-blind peer-review process, the editors rejected five chapters.

CHAPTER OVERVIEW

In Chapter 1, "Effects of Public Capital Investments on Productivity of the United States, 1992-2022," Brian Sloboda and Yaya Sissoko provide an in-depth analysis of public sector productivity in the United States from 1992 to 2022, a period characterized by significant heterogeneity across states in terms of public services delivery. This diversity has implications for both productivity and efficiency within the public sector. The chapter addresses the increasing scrutiny of public services amidst ongoing reform processes. Unlike the private sector, where market forces primarily inform performance, the public sector relies on comparative performance measures to assess productivity. This study investigates the productivity of the public sector across various states using standard Data Envelopment Analysis (DEA) and the Malmquist Productivity Index (MPI) for efficiency measurement. The DEA analysis is complemented by panel regression analysis to provide a more comprehensive understanding of public sector productivity, considering the unique challenges and dynamics of public service delivery in different states. This approach offers valuable insights into the performance of the public sector, highlighting areas for improvement and reform in the context of an evolving administrative landscape.

In Chapter 2, "Data Envelopment Analysis Advantages and Problems Demonstrated in a University Comparison Study," Kenneth David Strang explores the multifaceted aspects of DEA, presented in a manner accessible to a diverse audience, including business professionals, students, and various stakeholders. This chapter intricately explores DEA's input and output-oriented approaches, encompassing a spectrum of returns to scale – constant, variable, and those exhibiting increasing or decreasing trends. Crucial concepts such as radial movements and slack estimates are elucidated, paving the way to achieving an efficient frontier. Central to the discussion is the application of DEA through two distinctive datasets: a concise, illustrative example and a more extensive, real-world dataset derived from secondary higher education statistics provided by the U.S. Department of Education. This exploration offers a comparative perspective between DEA and nonparametric statistical methods. Furthermore, this chapter addresses the inherent challenges associated with utilizing DEA, highlighting the importance of employing methods and data triangulation to assure the reliability and validity of findings. One of the most striking revelations of this study is the inability to conclusively answer the research questions posed, underscored by independent data, which paradoxically presented contrasting results for some instances within the sample data. This chapter promises to be of significant interest to a wide array of individuals, including managers, decision-makers across various industries, students, government regulators, and researchers, providing them with valuable insights into the application and nuances of DEA.

In Chapter 3, "Productivity Profiles of Islamic Banks using Data Envelopment Analysis-Based Malmquist Productivity Indices (MPIs): Survey, Classification, and Critical Analysis," Karim Iddouch, Khalid El Badraoui, and Jamal Ouenniche present an in-depth systematic literature review focusing on the productivity of Islamic Banks (IBs). The study, which scrutinizes 68 publications from 2006 to 2022, emphasizes explicitly using Malmquist Productivity Indices (MPIs) estimated through DEA methodologies. The authors have meticulously categorized the existing literature into four distinct areas: the types of DEA analysis employed, the methods used for measuring productivity, the variables involved in DEA model specification, their evaluation approaches, and the underlying drivers and theoretical frameworks of productivity. Additionally, the chapter critically examines the literature to unearth gaps, inconsistencies, and potential sources of discrepancies, thereby shedding light on areas that future research might explore further to enhance our understanding of productivity in Islamic Banks.

In Chapter 4, "Efficiency Analysis of a Surgery Roadmap Based on Lean Manufacturing Techniques, Simulation, and Data Envelopment Analysis (DEA)," Leonardo H. Talero-Sarmiento and Laura Yeraldin Escobar Rodriguez focus on optimizing healthcare processes, particularly in the context of surgery roadmaps within healthcare systems. The study addresses the challenges of optimization in scenarios characterized by limited information. This chapter explores various methodologies, including lean manufacturing, operational research, simulation, DEA, and non-dominance analysis, to enhance efficiency and resource utilization in healthcare. The study identifies 32 interrelated patient pathways, revealing the shared activities and the extensive impact of optimization strategies across multiple routes. Unlike conventional analysis of pathway performance, this study utilizes DEA across various investment scenarios, offering vital insights for healthcare decision-makers on enhancing patient care quality and efficiency. The novel approach of combining DEA with a non-dominance algorithm provides a comprehensive and robust framework. This mixed-method approach is particularly effective in tackling operational challenges in healthcare, especially in situations of limited information, and underscores the importance of continuous process improvement.

In Chapter 5, "Synthetic Data Generation: Methods, Applications, and Multidisciplinary Use Cases," Edlira Martiri provides an in-depth examination of the current state of synthetic data generation, en-

compassing its methodologies, applications, and challenges across various scientific fields. This chapter addresses the growing need for synthetic data, driven by concerns over data privacy, limited availability of real datasets, and the requirement for diverse, representative data. The chapter explores a range of methods for generating synthetic data, including statistical modeling, generative adversarial networks (GANs), simulation-based approaches, and DEA. This chapter also discusses the importance of evaluating synthetic data in terms of quality and privacy preservation. Key applications in sectors such as healthcare, finance, social sciences, and computer vision are highlighted, along with emerging trends like the integration of deep learning and domain adaptation. The chapter is a valuable resource for researchers, practitioners, and policymakers, offering insights into the advanced practices of synthetic data generation.

In Chapter 6, "Data Envelopment Analysis-Based Approach for Maximizing Energy Efficiency in Ad Hoc Networks," Muhammed Abiodun Adebimpe, Adeyemi Abel Ajibesin, and Franklin Tchakounté explore the escalating energy demands of wireless networks driven by global population growth and urbanization, which have led to increased internet usage. The chapter underscores the growing importance of energy efficiency, especially in wireless networks, in response to rising costs and the need to reduce emissions. It focuses mainly on ad hoc wireless and sensor networks. The study employs computational methods and data envelopment analysis (DEA), incorporating Multicast Incremental Power (MIP) and Coded Packet algorithms as inputs to DEA to optimize energy efficiency while maximizing network resources such as node numbers. An output-oriented DEA approach is highlighted, aiming to enhance network performance by increasing output while conserving input resources. This research provides significant insights into the energy efficiency of wireless networks, offering practical guidance for network administrators and decision-makers, with a particular emphasis on ad hoc wireless networks.

In Chapter 7, "Efficiency Benchmarking Through Data Envelopment Analysis: Evaluating Disruptive Technologies in India's Key Sectors," Rajasekhara Mouly Potluri and Narasimha Rao Vajjhala provide an in-depth analysis of how disruptive technologies, including artificial intelligence, big data analytics, virtual reality, and drone technology, are reshaping lifestyles and employment dynamics in India. This chapter explores these innovations' history, meaning, theory, and significance, explicitly focusing on their transformative impact on critical sectors such as industry, healthcare, transportation, and energy in India. Employing DEA for efficiency benchmarking, the study systematically evaluates the extent to which these sectors have effectively leveraged disruptive technologies. The analysis highlights the various challenges, opportunities, changes in employer-employee relationships, and governance issues that have emerged from integrating these technologies. Additionally, the chapter examines the real-world applications of these innovations, emphasizing their implications for cost reduction, sustainability, and socially responsible practices in the respective sectors.

In Chapter 8, "Data Envelopment Analysis for Improving the Microgrid Operations," Uetutiza C.C. Kuzatjike and K.S. Sastry Musti explore the application of multi-objective DEA in managing and optimizing energy resources in microgrids, with a particular focus on off-grid settlements. Microgrids, which can be powered by a mix of renewable and non-renewable energy sources, offer a sustainable and reliable energy supply but pose significant scheduling and management challenges due to various constraints. The chapter demonstrates how DEA, a well-known solution methodology, can be effectively used in energy management studies. Specifically, it applies a multi-objective DEA to a rural, remote microgrid in the Tsumkwe region of Namibia, which solar plants and diesel generators supply. This approach utilizes the DEA algorithm to identify the optimal configuration of the microgrid by considering technical, environmental, and economic factors. The study assesses the energy system's performance

under different conditions, including varying efficiencies, fuel consumptions, and generator capacities, providing valuable insights into optimizing energy management in remote microgrids.

In Chapter 9, "Advancing Supply Chain Efficiency and Sustainability: A Comprehensive Review of Data Envelopment Analysis (DEA) Applications," Natasha Cecilia Edeh provides an insightful examination of DEA within the realm of supply chain management. DEA, known for its non-parametric approach in evaluating productive efficiency involving multiple inputs and outputs, has significantly influenced both academic research and practical applications. The method is particularly adept at analyzing performance in organizations where complex input-output relationships are prevalent. One of DEA's key advantages is its user-friendliness and the flexibility it offers in criterion weighting, which simplifies the analysis by obviating the need for calculating production functions and provides comprehensive efficiency assessments. The chapter critically reviews existing research on DEA's application in supply chains, aiming to identify current practices, recent innovations, and methodologies. The central research question addressed is, "What are the latest advancements and methodologies in applying DEA to the supply chain?" This study contributes to a deeper understanding of the intersection of DEA and supply chain management, an area of great significance in the intricate landscape of modern business.

In Chapter 10, "Efficiency Assessment and Optimization in Renewable Energy Systems Using Data Envelopment Analysis," Tarun Kumar Vashishth, Vikas Sharma, Kewal Krishan Sharma, Bhupendra Kumar, Rajneesh Panwar, and Sachin Chaudhary explore the burgeoning field of renewable energy systems, spotlighting their role in combating climate change and reducing dependence on fossil fuels. A key focus is the utilization of DEA, a potent tool for evaluating and enhancing the efficiency of these systems within scientific, information technology, and engineering frameworks. The chapter provides a comprehensive overview of DEA, covering its fundamental principles, methodologies, and models, and specifically discusses its application in the context of renewable energy systems. It also examines how DEA can be integrated with other analytical tools, such as life cycle assessment (LCA) and optimization techniques, to further refine the efficiency assessment of renewable energy sources. Additionally, the chapter addresses challenges related to data availability and quality and outlines potential avenues for future research in applying DEA to renewable energy systems. This exploration is essential for advancing the efficient and effective use of renewable energy in an era increasingly focused on sustainable practices.

In Chapter 11, "Data Envelopment Analysis in Healthcare Management: Overview of the Latest Trends," Narasimha Rao Vajjhala and Philip Eappen provide an insightful exploration of DEA within the context of healthcare management. DEA, recognized for its non-parametric approach in assessing the efficiency of decision-making units, is widely applied in various healthcare sectors, including hospital management, nursing, and outpatient services. The chapter synthesizes findings from numerous studies, emphasizing DEA's crucial role in efficiency measurement, benchmarking, resource allocation, optimization, and performance evaluation in healthcare. Despite its extensive use, the chapter also sheds light on several limitations and challenges associated with DEA. These include issues related to the selection of inputs and outputs, sensitivity to outliers, an inability to deal with statistical noise, the absence of measures for inherent uncertainty, assumptions of homogeneity, and the static nature of traditional DEA models. These identified challenges highlight the necessity for ongoing research and methodological improvements in applying DEA to healthcare management, aiming to enhance its effectiveness and reliability in this critical sector.

In Chapter 12, "Exploring Productivity by Evaluating ISP Efficiency in Nigeria's Telecommunications Sector," Yakub Akinmoyede, Adeyemi Abel Ajibesin, Senthil Kumar Thangavel, and Ridwan Salahudeen address the digital divide in Africa, specifically focusing on the efficiency of Internet Service Providers

(ISPs) in Nigeria. The research evaluates the performance of major Nigerian ISPs - MTN, Glo, Airtel, and 9mobile - using Data Envelopment Analysis (DEA). The study investigates key efficiency metrics, including internet speed, cost of data, years of operation, and subscriber base, over five years from 2015 to 2019. The findings indicate diverse efficiency levels among the ISPs, with MTN emerging as the most consistently efficient provider. These results significantly enhance internet service quality and foster competitive practices in Nigeria's telecommunications sector. The study underscores the importance of considering a range of factors in evaluating ISP efficiency, providing insights for future research, and guiding potential regulatory actions by the Nigeria Communications Commission. This analysis is crucial for understanding and addressing the challenges of the digital divide in Nigeria and potentially other parts of Africa.

In Chapter 13, "Comparison of Cost and Profit Efficiencies of Indian Public Sector Banks in the Post-Reform Period," Vipul Gupta presents a comprehensive analysis of the cost and profit efficiency of Public Sector Banks (PSBs) in India in the aftermath of the banking sector reforms introduced in 1991. The study covers a period from 1995 to 2017, which includes the post-liberalization era and extends up to the significant merger of the State Bank of India in 2017. It entails a year-wise examination of average profit efficiency (PE) and cost efficiency (CE) scores for each PSB in India. Additionally, the distribution and median of these efficiency scores across two sub-periods were evaluated using non-parametric methods, specifically Friedman's two-way ANOVA and the Wilcoxon signed-rank test. The findings highlight a trend of profit inefficiencies among PSBs during the selected period, with PE scores generally being lower than CE scores. The study also reveals considerable variations in efficiency among different Public Sector Banks throughout the 1995-2017 timeframe. Notably, there has been a decline in the PE of PSBs since the onset of banking sector reforms in 1991, offering critical insights into the impacts of these reforms on the operational efficiencies of India's PSBs.

In the book's final chapter, "Impact of Mergers and Acquisitions on the Shareholders Wealth of Indian Banks: A Data Envelopment Analysis Approach," Trilochan Jena, Pradipta Kumar Sanyal, and Sree Kumar present a study on the impact of mergers and acquisitions (M&A) on financial performance efficiency in the Indian banking sector, a domain marked by intense competition and dynamic changes. This study analyzes four major Indian banks —State Bank of India, Bank of Baroda, HDFC Bank, and Kotak Mahindra Bank—selected based on their market capitalization and focuses on the period between 2006 and 2018. It evaluates the financial efficiency of these banks over five years, both before and after the mergers, to assess the effects of M&A. The authors incorporate seven critical variables that influence the performance of these banks. Using the non-parametric method of Data Envelopment Analysis (DEA) for efficiency measurement, the study concludes that mergers and acquisitions positively impact banks' financial efficiency, highlighting the strategic value of M&A in enhancing performance in the competitive Indian banking landscape.

This book is the product of contributions from leading experts in the field. It is designed to be a valuable resource for those new to DEA as well as for seasoned practitioners and researchers seeking to deepen their understanding and application of this methodology in science and engineering contexts. We hope that this book will inspire new research directions, foster the development of innovative applications of DEA, and contribute to the broader discourse on efficiency and productivity in the scientific and engineering communities.

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Preface

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