Introduction and Overview

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> The health of the people is really the foundation upon which all their happiness and all their powers as a state depend.
>
> – attributed to Benjamin Disraeli[1]

Health is central to human well-being. It is also inextricably bound to productivity and economic development, both at an individual and an aggregate level: a family, a community, a country, and the whole world. Therefore, pursuing the goals that lead to and ensure a healthy population is paramount for society. The healthcare system is, by and large, the main vehicle for reaching such goals and its success largely depends on how productive, efficient, and effective its operations are in delivering the best possible outcomes. This is also what has motivated the idea and the work on this handbook.

In a nutshell, in this handbook, we bring together review-style chapters that illustrate three key notions and aspects of humanity – productivity, efficiency and healthcare – to outline the current foundations and state of the art that future research can build upon. The handbook presents a good mix of academic and regulatory perspectives, with overviews of major evidence from international empirical applications. The core of the handbook consists of academically focused chapters, yet we also try to bridge and provide outreach to the practice and regulation of the industry, including a wide mix of international perspectives, covering different regions of the globe.

As a handbook, the general approach we take is to begin with several chapters on methodology (with a focus on healthcare) that include the following topics:

[1] This well-known quote is attributed to the famous 19th century politician: Benjamin Disraeli, 1804–1881, British Prime Minister (Tory), July 24, 1877 speech, https://quote.org/quote/the-health-of-the-people-is-really-311896.

- Basic analytics for healthcare and hospitals
- Cost effectiveness for healthcare analysis
- Quality adjusted life year (QALY)
- Economic efficiency of policies to reduce ill health caused by environmental factors
- Measurement of health services in the national accounts
- Healthcare as social infrastructure and UK NHS
- Health, human capital, and economic growth
- Review and bibliometric analysis of the literature on efficiency and productivity in healthcare
- Overview of production theory
- Data envelopment analysis (DEA) for healthcare analysis: Theory and applications
- Statistical aspects (consistency, asymptotic distribution, and bootstrap methods) for DEA with application to hospital performance
- Stochastic frontier analysis (SFA) for healthcare analysis: Theory and applications
- Quantile-type and conditional frontier approaches with empirical illustration for the healthcare context
- Guidelines for measuring health and healthcare efficiency
- Causal inference in healthcare
- Queueing theory and application to dynamic assignment of patients to inpatient units

WHY IS SUCH A HANDBOOK NECESSARY?

There is a clear niche for such a handbook: Extensive research has been done in productivity and efficiency in general and their applications in healthcare in particular, yet to our knowledge there is no recent handbook that covers this research in a coherent and comprehensive manner.

Comparable Volumes and How the Handbook Fits Within the Literature?

Our handbook is aimed to be a broader, much more comprehensive, and more up-to-date analogue of the book by Hollingsworth and Peacock (2008), and it is put together in a style somewhat similar to *The Oxford Handbook of Productivity Analysis*, edited by Grifell-Tatjé, Lovell, and Sickles (2017). The latter is a general handbook on productivity and efficiency analysis, whereas our handbook is more focused (and more recent) and fine-tuned to productivity and efficiency analysis in the context of healthcare. Importantly, most chapters of our handbook provide more recent and more concise discussions of both theoretical and applied aspects than other good books in the field of productivity analysis (and therefore complement them well), including books

by Balk (1998), Färe, Grosskopf, and Lovell (1994), Färe and Primont (1995), Kumbhakar and Lovell (2000), Fox (2002), Ray (2004), and Sickles and Zelenyuk (2019), to mention a few.

Our handbook is also a good complement to many good books and handbooks dedicated to healthcare economics, such as Culver and Newhouse (2000), Jacobs, Smith, and Street (2006), Glied and Smith (2011), Strome (2013), and Aizcorbe, Colin Baker, Berndt, and Cutler (2018), to mention just a few. Many other references can be found in the handbook chapters.

A Brief Overview of the Handbook

Here we provide a brief overview of each chapter, providing a quick glimpse into the interesting discussions that are awaiting the readers of this handbook.

Chapter 1, titled "Overview of Performance Analytics for Healthcare with Examples in R," is coauthored by Zhichao Wang and Valentin Zelenyuk, who provide a more technical introduction to the handbook theme: analysis of performance of the healthcare sector. The chapter begins with a brief overview of recent international trends in healthcare expenditures, which display the rapid, widespread increases in per capita healthcare expenditures as well as the disparities in those expenditures across countries. This motivates one of the main goals of the handbook in general and this chapter in particular, which is to introduce the wide range of methods used for understanding these trends (i.e., performance analysis in healthcare). This chapter is a primer for what follows.

The analysis of performance in healthcare is dependent on available data as well as various mathematical and statistical techniques to assess that data, for example, to reveal possible sources of inefficiency. The authors begin the overview of methods used to assess performance with the most basic: ratio analysis. Examples include occupancy rate (average utilization of beds in a specific healthcare facility during a specified period) and average length of stay per patient. These may be thought of as key performance indicators (KPIs) and have the advantage of being easy to understand, but they do not provide a measure of overall performance. Balanced scorecard methods evaluate hospital performance using the KPIs to provide multiple dimension assessment. Cost-effectiveness analysis is yet another approach they discuss briefly, which focuses on the comparison of estimated health benefits (which are difficult to measure) to associated costs. This approach is then discussed in greater detail in Chapter 2, authored by Stephen Birch and Amiram Gafni. Wang and Zelenyuk also briefly discuss QALYs and refer to Chapter 3 by Han Bleichrodt and John Quiggin, who discuss this important topic in greater detail.

Frontier methods are most closely associated with efficiency as a performance measure – the topic that Wang and Zelenyuk consider next. In particular, they provide introductions to the two most popular versions of frontier methods: data envelopment analysis (DEA) and stochastic frontier analysis (SFA). DEA is a nonparametric, deterministic approach, meaning it does not

provide estimates of prespecified parameters of a cost or production function. Its roots are closer to operations research than econometrics, in contrast to SFA. However, both characterize efficiency with respect to how far a particular observation (such as a hospital) is from the best practice of the hospitals in the sample. The chapter also briefly discusses hybrids of DEA and other statistical methods. These approaches are later discussed in greater detail: Chapters 9–12 focus on DEA, Chapter 13 and 14 focus on SFA, and Chapter 15 presents some hybrids of these two approaches.

Much of the available data is related to hospital operations; Chapter 1 provides empirical examples for Australian hospitals of these different approaches to assessing healthcare performance, including the R code used to create them, which applied researchers may find of additional value.

Chapter 2, titled "Cost-Effectiveness Analysis for Healthcare: From Theory to Practice to Problems and Solutions," is coauthored by Stephen Birch and Amiram Gafni. These authors present a comprehensive review of cost-effectiveness analysis (CEA), a well-known methodology widely applied in the healthcare sector. Following the framework set out by Weinstein and Zeckhauser (1973), Birch and Gafni effectively tie together the economic justifications used by decision-makers in determining the effective use of various medical technologies and opt for the one in which health outcomes are optimal.

The authors introduce the typical measurement techniques used by decision-makers, including league tables and incremental cost effectiveness ratios (ICERs, defined as the mean cost per additional life year produced). These are used to justify investments in new interventions. Birch and Gafni also show how relaxing overly restrictive assumptions (divisibility, constant returns to scale, endogeneity, and thresholds) can lead to better solutions. Demonstrated by both a written description of these various assumptions and graphical representations, the authors provide valuable background for health economists in assessing how best to allocate scarce resources, which is particularly important to decision-makers given budget constraints.

This chapter, along with Chapter 3 on Quality QALYs, by Bleichrodt and Quiggin and Chapter 10 on the evaluation of the production process for the treatment of psoriasis by Rikard Althin, Rolf Färe, Shawna Grosskopf, and Marcus Schmitt-Egenolf, provides future researchers with a firm foundation for designing a useful policy tool that can be used in making decisions regarding the best medical interventions to pursue.

Chapter 3, titled "Capabilities, QALYs, and COVID," is coauthored by Han Bleichrodt and John Quiggin, who lay out an effective application of Amartya Sen's capability framework, which is often used to rank capability as applied to QALYs. The framework as demonstrated in this chapter illustrates how QALYs can be validated as a measure to determine the willingness to pay for them. The authors carefully take the reader step by step, starting from assessing initial endowments to achievable endowments based on the spending of wealth on goods and services including healthcare. Focusing on COVID, the authors

raise interesting philosophical issues distinguishing individual utilities from social-welfarism as set out by Sen. Given that the recent COVID-19 pandemic raised issues of public health versus individual choice, the authors illuminate a succinct and persuasive argument for their approach. In conjunction with the other chapters that include QALYs as an important measurement of outcomes, future researchers can use the methods described here to formally provide persuasive arguments for public input into healthcare services. This is particularly helpful for individuals researching healthcare effectiveness in countries where healthcare services are primarily provided by the public sector and where the impact of diseases such as COVID-19 spill out into society.

Chapter 4, titled "The Economic Efficiency of Policies to Reduce Ill Health Involving Environmental Factors," is authored by Clement Tisdell. This chapter focuses on adverse health effects caused by environmental factors and how economic tools related to efficiency might inform policies to improve resulting health outcomes. Tisdell addresses a variety of environmental factors affecting health, including the public supply of safe water, sanitation, and environmentally related diseases, which typically include externalities. Examples discussed include cadmium poisoning, drinking water contamination (recall the Flint, Michigan crisis), and issues associated with COVID-19, such as the willingness of individuals to vaccinate. (In his 2020 article, "Economic, social and political issues raised by the COVID pandemic" in *Economic Analysis and Policy*, he provides a detailed and prescient discussion of this topic.)

Tisdell uses approachable graphics to illustrate the various economic efficiency tools used to analyze the aforementioned cases. He concludes that simple production functions may be helpful in the case of the public supply of safe water, but cases with environmental spillovers, such as cadmium poisoning, require more holistic social economic efficiency approaches such as social cost-benefit analysis. Yet, he reminds us that the estimation of social benefits is difficult, and if based on Paretian potential improvement, this may increase the inequality in the allocation of public health resources. This was also a concern in the Flint contamination of drinking water from lead when authorities switched to a cheaper water source to save money.

In addition, particular attention is paid to problems involved in determining the social economic efficiency of the amount and use of methods of controlling environmentally related diseases when their effectiveness declines with use. The importance of this analysis is illustrated by considering the resistance of bacteria to antibiotics with its common-pool property and by the discussion of the methods of controlling the incidence of malaria. It is argued that, despite the presence of bounded rationality, assessments of economic efficiency need not be complete in order to provide worthwhile evaluations of public health policies.

Chapter 5, titled "Health in the National Accounts," is authored by Paul Schreyer, who writes about the importance and the challenges of measuring healthcare services on the country level as well as across countries. It is worth

noting a distinctive feature of this chapter: Unlike other chapters written by academicis, this chapter is authored by a seasoned practitioner in the business of measuring healthcare services across countries who served as the chief statistician and director of statistics and data directorate of the Organization for Economic Cooperation and Development (OECD). In addition, his advanced academic knowledge brings a unique perspective.

This chapter concisely clarifies the key and subtle matters of terminology as well as the main methods and practices employed. Also included are related statistical issues that affect the resulting precision of measurements. In particular, Schreyer starts by pointing out that healthcare services represent a major economic activity for a country, thus emphasizing the importance of its precise measurement in the national accounts. He then describes the complexity of this task, pointing out issues that are in addition to the standard technical issues pertinent to measurements with statistical indexes. These include high heterogeneity of activities (including latent quality of outputs), amplified by significant, and sometimes rapid technical changes in the healthcare sector.

The author also points out that one key reason for the complexity is that a large share of activities in the healthcare sector occurs in a nonmarket setting. Moreover, there is a substantial difference between the producer perspective (which is more amenable to measurement) and the consumer perspective (which ultimately may be more relevant for society). The author concludes with a short overview of how measurement practices vary across different countries, which is particularly useful for those wishing to pursue cross-country comparisons of healthcare. Although the discussion is relatively brief, Schreyer also provides many valuable references where more details can be found.

Chapter 6, authored by Diane Coyle, is titled "Healthcare as Social Infrastructure: Productivity and the UK National Health Service During and After COVID-19." In this chapter, as the title suggests, the author brings attention to the healthcare system from the point of view that it is an important part of the national social infrastructure. To emphasize her main points, the author's focus is the period during the surge in demand due to the COVID-19 pandemic and its impact on the National Health Service (NHS) of the United Kingdom.

In the chapter, the reader will find interesting discussions of various aspects of performance of the health service: cost efficiency, human capital investment, resilience, long-term need, NHS productivity, as well as economy-wide productivity. Although the focus is on the UK's healthcare system, the reader will notice that many (if not all, at different degrees) aspects discussed are analogous to healthcare systems of virtually any other country, whether developed or developing. In particular, one of the key points raised by the author is that the decade of austerity budgets preceding the pandemic led to "severe financial squeeze" and "under-funding relative to need and demand." In turn, this left the system without much (or any) spare capacity (e.g., as measured by beds per capita and doctors per capita). While comparing the UK to other countries, the author points out that the worst-performing countries on their

health outcome measures (excess mortality scores) include Peru along with four OECD countries: Spain, the UK, Belgium, and Italy.

Overall, the author concludes that policymakers "need to consider the health system as social infrastructure, rather than as a service to be driven for maximum short-term efficiency… [and thus should] take into account the need to deliver resilience, to accommodate demand peaks, and to consider its contribution to whole economy growth and productivity in determining investment levels."

Chapter 7 is titled "Health, Human Capital and Its Contribution to Economic Growth." As in Chapter 5, it presents a perspective from a leading nonacademic expert, Wulong Gu from the Economic Analysis Division of Statistics Canada. In this chapter, Gu presents a novel view on how health expenditures should be classified in the national accounts.

In particular, the author explains that the standard practice is to view expenditures on health (as well as education) as "current expenditures rather than investment" (e.g., see Chapters 5 and 6 and our introduction to them here) and then argues that at least some of these expenditures should be regarded as consumption aimed at improving the consumer's well-being. More specifically, the author follows the Jorgenson-Fraumeni income-based approach, which is designed to account for the effect of health on human capital. Gu also proposes extending the approach, providing a new framework for estimating health improvement, such as, for example, improvements of life expectancy and reduction of morbidity rates. (See related discussions about QALY in Chapter 3.)

The author illustrates this novel approach for the case of Canada, estimating investment in the health of human capital for the period between 1970 and 2020. Interestingly, the last year of this study period includes the beginning of the COVID-19 pandemic, where the author finds a substantial decrease in the health of human capital, driven by a mortality rate increase. The author also finds differences in investment in health capital between men and women throughout the whole period.

Finally, the author concludes that "much of health expenditures should be classified as consumption rather than investment that increases the earnings. Much of the effect of health expenditures is noneconomic and is reflected in the improvement in the quality of life and the well-being of individuals."

Chapter 8, titled "What Do We Know From the Vast Literature on Efficiency and Productivity in Healthcare? A Review and Bibliometric Analysis," is coauthored by Kok Fong See, Shawna Grosskopf, Vivian Valdmanis, and Valentin Zelenyuk. As the title suggests, the authors take on the challenging task of reviewing the immense literature for the field of efficiency and productivity in the context of healthcare. To achieve their goal, they deployed machine-learning methods to unveil interesting patterns and insights from the data.

More specifically, they identified and analyzed a set of 1,059 articles published in Scopus-indexed academic journals between 1983 and 2021

(which were produced by over 2,000 authors) that focused on efficiency and productivity in the context of healthcare. To do so, the authors deploy the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) procedure for bibliometric studies, along with various tools of modern biblioanalytics to support the understanding and descriptions in the literature. Among the highlights are

- publication trends in healthcare efficiency and productivity studies;
- geographical contribution to publications;
- analysis of most influential authors and their collaboration networks;
- analysis of most influential institutions and their collaboration networks;
- analysis of most influential countries and their collaboration networks;
- analysis of most influential journal articles;
- analysis of most influential journals in healthcare efficiency and productivity studies;
- analysis of citation network (threshold = 80 citations); and
- analysis of keywords (including keyword networks), overall and with separate focuses on developed and developing countries.

Of particular value is the summary of key findings from the 10 most cited articles in the field of efficiency and productivity analysis in healthcare, which the authors present in Table 8.7, along with the related discussion.

The readers will notice that in the past four decades, the most popular approach in the field of efficiency and productivity in the context of healthcare was DEA, followed by SFA. This is what motivated us (the editors) to dedicate the next four chapters of this handbook (9–12) to DEA, two chapters (13 and 14) to SFA, and Chapter 15 to what can be viewed as hybrids of these two popular approaches. Those are then complemented by Chapter 16, where Bruce Hollingsworth presents his views on the guidelines for measurement related to DEA, SFA, and more generally.

Chapter 8 also provides some of the authors' thoughts about the trends and likely (or wishful) future avenues of research in the field of efficiency and productivity in the context of healthcare. We hope the chapter will be a valuable primer for researchers just starting in this field as well as those who have been in it for some time so that they can see (both intuitively as well as literally, i.e., visually) where the literature was, where it is now, and perhaps, where it is going.

Chapter 9, titled "Brief Overview of Production Theory for Analysing Healthcare Performance," is presented by long-time coauthors in the field, Rolf Färe and Shawna Grosskopf. The goal of the chapter is to introduce the readers to what they call the "basic production theoretical underpinnings used in modeling and measuring performance in the healthcare realm, which covers a host of institutions, practitioners, regulators, insurers, and patients among others." It is worth noting that such underpinnings are based on a vast general literature in economics/econometrics, operations research, and management

science, which requires volumes to describe (a few of which were written by these coauthors). Hence, as the authors admit, it is a challenging task, amplified by the complexity of the healthcare sector. In a sense, and similar to other chapters, the authors hope to save the reader from being overwhelmed by the vast literature at the outset by providing a more user-friendly overview with many references for further details.

The authors begin with an introduction of the axiomatic approach to general production theory, describing it in the context of modeling the healthcare sector. They start with modeling the production via multi-dimensional sets and then move to a discussion of functional representations of these sets via production functions, distance functions, and their dual value functions (cost, revenue, and profit functions) and the related efficiency measures. After a brief discussion of the parametric representation of these functional representations, the authors move to the basics of DEA and some of its popular variations. They clarify that DEA is rooted in the activity analysis modeling approach developed in economic theory (around the 1950s) and is an estimation approach based on the linear programming approach, developed and popularized by researchers and practitioners of operations research, management science, as well as economics. The authors also briefly discuss the measurement of dynamic aspects of efficiency and productivity, using the example of the Malmquist productivity index. They finish with a concise discussion of key limitations of DEA and further extensions that aim at overcoming those limitations and refer to other chapters of this handbook that discuss those aspects in greater detail.

Chapter 10, titled "Modeling of Well-Being from an Intermediate Medical Intervention," is coauthored by Rikard Althin, Rolf Färe, Shawna Grosskopf, and Marcus Schmitt-Egenolf, who assess the theoretical production applications to the treatment of psoriasis exclusively. Inputs include physician input and pharmaceutical interventions, most notably biologics. Psoriasis is a condition in which skin cells build up and form scales and is considered a health problem associated with the immune system of the patient. Biologics are developed from a variety of natural sources and have been prescribed for the treatment of psoriasis. The authors effectively demonstrate the measurement of how productivity approaches can be used to isolate the benefits from the use of inputs to gauge the output, such as a decrease in patient illness severity. Using a comprehensive database, the Register for Systematic Treatment for Psoriasis, the authors meticulously demonstrate how they extracted the data for the final number of patients analyzed. Further, a strong argument is made for using this approach when random clinical trials are not available for measuring treatment effectiveness. Their results demonstrate that not only were certain treatment regimens beneficial for relieving symptoms of psoriasis via improved well-being and health but also that these treatment regimens met the productivity definition of improved efficiency.

Further, this chapter is particularly relevant for any future researcher wishing to assess the economic benefits for any particular medical intervention in

improving health. As such, this chapter meshes with the other chapters in this handbook, notably the chapters addressing QALYs (by Bleichrodt and Quiggin) and cost-effectiveness analysis (by Birch and Gafni). Taken together with the methods demonstrated in other chapters, this chapter will provide a useful framework for comprehensive development of measuring health improvements with effective and efficient medical treatment.

Chapter 11, titled "Data Envelopment Analysis Applications and US Hospital Policy," is coauthored by Vivian Valdmanis, Shawna Grosskopf, Valentin Zelenyuk, and Gary Ferrier. It provides a selective review of envelopment analysis (DEA) research with a focus on US hospital performance in terms of efficiency and productivity and its hospital policy implications. The key characteristics of US healthcare in general and hospitals in particular are their high and growing costs as well as the variation in quality and access to that expensive care.

This chapter may prove especially helpful to the international readers not familiar with the unique characteristics of US hospitals: It provides a brief history of the rise of hospitals in the US and a concise summary of legislation passed between 1946–2012 (e.g., see their Table 11.1), which affected US hospital policy in general and key three aspects (costs, quality, and access to care) in particular. The chapter also provides a quick public policy process review, which suggests that DEA can contribute to informing policy at each step of the process, from specification of the problem to evaluation of implementation.

After an overview of US healthcare and hospital expenditures since 1960, the authors discuss trends in the rather uniquely complex pattern of US health insurance coverage by type. In particular, they point out that despite efforts by various administrations, the US does not have universal healthcare insurance. Another rather unique feature of the US hospital system is the variety of ownership forms: proprietary (private-for-profit), local public, and not-for-profit, which have often been compared in terms of their costs and efficiency.

Returning to the key policy issue (i.e., hospital costs), they turn to studies that use DEA to provide insight into the sources of high costs. This covers various DEA approaches: basic technical efficiency seeking reductions (increases) in inputs (outputs), plant capacity utilization that identifies "excess capacity," as well as Malmquist productivity index applications that allow for performance assessment over time. The chapter next takes up DEA studies that attempt to account for quality of care in assessing performance. The authors point out that the first hurdle is to define and measure quality of care. Many of the studies they discussed are fairly recent, exploring recently available data required in 2003 by Medicare on quality characteristics, including quality of inputs/processes as well as outcomes measured in terms of readmission rates, excess mortality rates, and patient satisfaction among others.

Given the basic reality in the US of the lack of universal healthcare, the issue of access to healthcare matters is the next and final key aspect discussed by the authors. They point out that the role of health insurance is of key importance in