1. Introduction

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Measurement of productivity and efficiency of companies, institutions and various other enterprises is a well-defined area of economics. This area of research and practice, which started around the mid-1950s, is now a standard tool in national accounting and in various assessments of economic sectors or individual enterprises (Fried et al., 2008; Peacock et al., 2001).

The development of productivity and efficiency theory and practice has coincided with a period in human history that has perhaps witnessed the largest ever extent of anthropogenic environmental change. Consequently, environmental conditions and the effects that various human economic activities impose on the environment have become of key concern to society. Standard methods of productivity and efficiency analysis are, in general, not designed to consider these environmental considerations.

In response, the concept of environmentally adjusted productivity analysis and efficiency measurement has been rapidly developing since the early 1990s. This approach is addressing the need to account for environmental impacts from various economic activities in human society. This is becoming increasingly important as the environment and the ecosystem services it provides are significantly threatened by air pollution, land degradation, deterioration of water quality and biodiversity losses. In this light, a fundamental question is how to accommodate environmental effects into the standard practices for measuring productivity and efficiency. This book explores some new ways of addressing that question.

Over the recent years, there has been a growing debate in the literature about how to most effectively incorporate the environmental effects from production activities in economic models designed to measure productivity and efficiency (Färe et al., 2013; Kumar and Khanna, 2009; Zhou et al., 2008; Coelli et al., 2007; Ball et al., 2004). A variety of existing methodological approaches – including those based on index number theory, stochastic production frontier, and non-parametric approaches – have been adapted to serve the purpose of measuring environmentally adjusted

efficiency of various units of observation (e.g. firms, industries, or countries). A number of recent papers have identified some drawbacks of the existing models and proposed alternative approaches to measure environmentally adjusted production efficiency (e.g. Abad, 2015; Azad and Ancev, 2014; Hoang and Thanh, 2013).

In addition, the UN Statistical Commission has recently adopted an international standard accounting approach – the System for Environmental-Economic Accounts (SEEA) – for incorporating environmental and natural capital into national accounting practices (European Commission et al., 2013). This has been followed by many national statistical offices that have started to incorporate environmental indicators in some components of national accounts.

This book offers a collection of chapters that address various conceptual, methodological and empirical aspects relevant to environmentally adjusted productivity and efficiency measurement. It provides a wide-ranging survey of the work on the intersection of environmental/natural resource economics and productivity analysis, which emphasizes the connection between the theory of economic efficiency and the measurement of environmental effects. The purpose of the book is to:

- take stock of the current state of environmentally adjusted productivity and efficiency literature;
- present some new approaches/methods that have been recently developed to estimate environmentally adjusted productivity and efficiency;
- present empirical studies that conduct environmentally adjusted productivity and efficiency measurements in a wide range of contexts.

The advances that this book is making are relevant to a broad array of applications, including air and water pollution, climate change, natural capital accounting, environmental regulation and the use of natural resources.

The book has a truly global appeal as it covers a range of empirical studies conducted in various countries across the globe – including Bangladesh, China, the US, Australia, Spain and Iceland – as well as comparisons across 32 Organisation for Economic Co-operation and Development (OECD) countries. This showcases the substantial international significance of the problems that this volume is addressing.

The book does not follow any particular structure, but the chapters are grouped in a logical sequence. At the outset, Chapter 2 provides an exhaustive overview of the environmentally adjusted productivity and efficiency models that have been reported in the economics literature. This is followed

by a group of three chapters that address specific methodological issues. A significant amount of work in environmentally adjusted productivity and efficiency measurement has been done in the agricultural sector, which is reflected in this book, with Chapters 6, 7 and 8 focusing on measures of agricultural total factor productivity and on accounting for natural capital in agriculture. The municipal water supply and wastewater sector has also been subject to numerous efficiency analyses, and Chapters 9 and 10 focus on this sector. Chapters 11 and 12 present important international applications of environmentally adjusted productivity and efficiency methods.

This book is making a contribution to knowledge by pointing out various ways of articulating the environmental issues in productivity and efficiency models. In this way, it enhances conceptual and applied knowledge by improving our understanding of how to couple standard economic models and frameworks with indicators for environmental effects and natural resource use.

In addition, several chapters of the book have strong policy implications that will help policymakers around the world in addressing environmental problems in an efficient way. The models presented in this book are applicable to a wide range of economic sectors where the reduction of environmental pressures from economic activities is needed, desired or implemented by different policy strategies. In the context of natural resource management, the ultimate aim of the authorities is to sustainably manage environmental resources at local or regional levels, and to attain the best possible economic and environmental outcomes. Environmental goals in many countries around the globe are concerned with ensuring that natural and environmental resources are managed efficiently, both in terms of quantity and quality. To achieve these objectives, many countries are currently adopting ambitious regulations whose design could benefit from improved understanding of the interactions between environmental and economic performance, which is the focus of this volume.

Several types of audience were kept in mind when preparing this book. Researchers and scholars working in the area of productivity and efficiency analysis are obviously a key audience who will benefit from reading this book. This includes postgraduate students and, to a certain degree, upper-level undergraduate students. Another important audience is practising statisticians and national accountants, who will find some of the chapters highly relevant for their work. This book will also appeal to quantitatively minded policy professionals working in government departments and international institutions who are interested in productivity and efficiency measurement and in accounting for environmental effects. Some members of the wider economics, ecological and environmental professions will also find this book appealing as it articulates together two

notions that are often seemingly irreconcilable: economic efficiency and environmental efficiency.

In what follows, we briefly introduce each of the remaining 11 chapters. Chapter 2 by Ancev, Azad and Akter provides a comprehensive review of the literature on environmentally adjusted productivity and efficiency since its inception in the early 1990s. This chapter also provides an overview of the key conceptual and methodological approaches that have been used in this literature. For those readers who are not familiar with the concepts of frontiers, distance or directional distance functions, or with the various productivity and efficiency indicators, this chapter will provide an excellent introduction that will make the rest of the book a much easier read.

Chapter 3 is authored by Färe, Grosskopf and Pasurka, and proposes a modification of the existing approaches to modelling joint production of good (desirable) and bad (undesirable) outputs in the context of pollution abatement. The chapter is motivated by the argument that traditional joint production models treat the process of transforming inputs into good and bad outputs as a black box, thereby clouding the crux of the problem. In order to investigate the consequences of this approach that ignores the transformation process, this chapter introduces a model of network technology that effectively looks inside the black box. It finds that the transformation process consists of a set of sub-technologies or sub-processes. After specifying both network and non-network models, the authors use a panel dataset of coal-fired power plants in the US to compare empirical results generated by the two specifications of the production technology. They find that the network models produce superior results.

This is followed by Chapter 4, authored by Fox and Lee, which focuses on the methodological problem of outliers in the data. In particular, the case where some firms may achieve relatively high/low levels of output due to environmental effects that are unrelated to their efficiency is examined. These firms may be treated as outliers. The chapter implements an innovative approach to outlier detection in two separate case studies, using data for a fishery and an irrigated agriculture industry. The detection of outliers allows either for an explicit adjustment of the scores for environmental factors or the exclusion of the outliers, and hence an implicit adjustment of the scores that would have otherwise resulted. This is very important for the quality assurance of sample data that forms the basis from which many agencies undertake productivity comparisons.

Chapter 5, authored by Edmonds, Lovell and Lovell, makes a methodological contribution by presenting procedures for creating ecological indexes that are invaluable as a representation of environmental conditions in environmentally adjusted efficiency studies. The specific indexes considered in this chapter measure the health of water streams using macroinver-

tebrate and fish diversity and abundance indicators. The authors specify three influences on stream health: an ecological connectivity index created by aggregating two indicators of in-stream longitudinal connectivity; a land cover index created by aggregating two indicators of land cover; and an upstream sub-catchment drainage area. Data envelopment analysis is used to create the indexes, and stochastic frontier analysis is used to explain variation in the two stream health indicators. The chapter relies also on dominance analysis, which is independent of the concept of a frontier and which provides the foundation for the evaluation of the ability to translate ecological connectivity, land cover and upstream drainage area to stream health.

The first in a series of three chapters that discuss the interface between environmental factors and agricultural productivity is Chapter 6, authored by Hoang and Wilson. This chapter describes a method based on the concept of material balance to derive environmentally adjusted efficiency measures in the context of agricultural production, where excess nutrients (nitrogen and phosphorus) and the emission of greenhouse gases are two notable environmental pressures. Malmquist total factor productivity indexes are used to derive environmentally adjusted efficiency measures. The empirical application is for the case of agricultural production in 32 OECD economies over the period 1992–2008. The findings show that the agricultural sectors of the OECD countries should have been able to produce the same output levels with significantly less nutrient input and emissions of CO₂. By improving materials-based efficiency, these countries could have reduced potential damage in the air, water and land systems.

This is followed by Chapter 7, by Obst and Eigenraam. The chapter articulates a conceptual approach to the integration of ecosystem services and ecosystem assets into standard national accounting practices. This is explored through an analysis of possible measures of environmentally adjusted agricultural productivity. The conceptual approach is explained through description of the treatment of soil degradation and the treatment of particular ecosystem services of relevance to agriculture, including pollination, water supply and nutrient absorption. The chapter also discusses the many conceptual and measurement issues that remain to be further explored.

Chapter 8 is authored by Hughes and Lawson and deals with measures of agricultural total factor productivity adjusted for climate change. This chapter makes a point that a significant part of the observed stagnant total factor productivity (TFP) measures of the agricultural sector in Australia can be attributed to the systematic worsening of the climatic conditions since the mid-1960s. The approach makes use of advanced quantitative methods based on machine learning to derive climate-adjusted estimates

of TFP in agriculture. The results show that, after adjustments are made for persistently worsening climate that can be attributed to climate change, the agricultural productivity in Australia has in fact experienced a good productivity growth. This highlights the importance of considering exogenous factors, like changing climate, in undertaking productivity analyses.

A pair of chapters that focus on efficiency of the urban water and wastewater treatment sectors starts with Chapter 9, authored by Hernández-Sancho and Bellver-Domingo. This chapter provides a comprehensive literature review of the productivity and efficiency studies in the urban water and wastewater treatment sectors. It then specifically focuses on the literature on environmentally adjusted productivity and efficiency measurement in these sectors. In this direction, a specific interest is in the extent of water leaks in the supply network. From an environmental point of view, leakages cause inefficient energy use in the water supply network and may also affect water quality by increasing susceptibility to contamination under low pressure conditions. The chapter evaluates the efficiency of municipal water suppliers in terms of water leakages, and demonstrates how inefficiency in the supply process can negatively affect urban water users.

This is followed by Chapter 10, by Hernández-Sancho, Lamizana-Diallo and Ingram, which demonstrates that the accurate assessment of the environmental and health costs of not taking action to improve wastewater treatment quality is necessary when evaluating suitable investment policies for an efficient wastewater treatment. Estimation of the environmental costs of no action can be based on the traditional approach, on the premise that economic value arises from the interaction between an individual and an environmental asset as an expression of an individual's preferences. An alternative approach is to estimate shadow prices of pollutants that are to be removed by an efficient wastewater treatment. This alternative method is derived from a 'cost of production perspective' and uses the concept of distance function to estimate shadow prices. These shadow prices represent the value of external effects that could damage the environment if wastewater is inefficiently treated. Several empirical applications verify the reliability and usefulness of estimating shadow prices of wastewater pollutants as a proxy to estimate the environmental costs of no action.

The discourse on shadow prices is continued in Chapter 11, authored by Hailu and Ma, but this time in the context of abatement cost of carbon dioxide emissions in China. China is now the leading source of carbon emissions, and has become the subject of a growing number of studies attempting to estimate marginal carbon abatement costs using distance functions. Provincial-level data for China are used to estimate the functions using mathematical programming (deterministic frontier) and

Bayesian methods (stochastic frontiers). Carbon abatement cost estimates in the form of shadow prices are compared to the values reported in the literature and to market prices for carbon. The Bayesian results are found to produce lower shadow prices that are closer to the observed market prices, compared to the estimates obtained through the use of mathematical programming.

The final chapter in the book, Chapter 12, is authored by Jahan and Ancev, and provides an application of the environmentally adjusted productivity and efficiency methods in the context of shrimp farming in Bangladesh. The chapter uses those methods to evaluate the economic and environmental efficiency of shrimp farms, which have become more numerous and more important for the economy of Bangladesh since the mid-1990s. At the same time, shrimp farming has been blamed for the serious environmental degradation in the areas where it has expanded. A directional output distance function approach is used to measure the efficiency of shrimp farms in the presence of desirable and undesirable outputs. The study covers the major shrimp-farming regions in Bangladesh and evaluates their performance at two time points, the years 2000 and 2010. An environmental efficiency index is estimated using alternative assumptions of weak and strong disposability of outputs. The results help identify areas where shrimp farming has been economically beneficial and has not caused large environmental damage, as well as areas where the opposite is true.

Overall, the 12 chapters of this book provide, in our view, a comprehensive coverage of theories, methods and empirical applications relevant to environmentally adjusted productivity and efficiency measurements. They also open up new horizons in terms of directions for future research in this rapidly growing area of knowledge. We believe that readers will find the volume informative, instructional and inspirational, and that they will find the investment in the time devoted to reading this book worthwhile.

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