

1 *The Environment and Externality*

An Overview

1.1 Introduction

Caring for the environment has long been part of the human ethos, and many cultures value the harmonious coexistence of humanity and nature. Nevertheless, exploiting the environment has been a recurring theme of economic development, particularly since the industrial revolution. Moreover, one group's desire for economic advancement is often at odds with another group's desire for a better environment. One of the early recorded examples of this friction comes from April 1739, when Benjamin Franklin led a petition to the Pennsylvania Assembly, protesting about a factory that was dumping waste in its local neighborhood (McMahon 1992). This was a clear case of one group's economic activities negatively impacting other people in the community by damaging their environment. Over the last two centuries, tensions between people's desires for economic advancement and society's aspiration to minimize the impact on the environment have regularly led to conflict.

Economic activities, such as production and consumption, often generate pollution and so economic decisions always include tradeoffs between the benefits of economic activities and the resulting pollution damage. Pollution control needs mitigation technologies. But environmental protection is more than a technology issue: pollution and its mitigation alter people's behavior and choices. When we scrutinize environmental issues in the societal context, they become economic problems, and environmental economics is the subfield of economic science that studies the economic issues related to environmental protection and pollution control.

Environmental economics has become an active and colorful subfield of economics since its inception in the early 1960s (Pearce 2002) and has found applications in all areas related to environmental protection. The research in environmental economics applies analytical

tools developed in other parts of economics to environmental problems. Positive economic theories buttress the analytical framework of environmental economics. Environmental policies rely on evaluation tools developed in normative economics and reflect environmental economics thinking on the implementation of pollution control technology. Environmental economics is diverse both in the issues it addresses and in the methods it applies. Nevertheless, some themes are universal in all areas of environmental economics research – externality is one of them.

External effects are ubiquitous socio-economic phenomena and many economic research issues are related to the theory of externality. In particular, externality is one of the main research topics in public economics. Externality is a broad and sometimes an equivocal concept. There are dozens of narrative definitions of externality. In an early attempt to pin it down, Meade (1973) defined “externality” as follows: “an external economy (diseconomy) is an event which confers an appreciable benefit (inflicts an appreciable damage) on some person or persons who were not fully consenting parties in reaching the decision or decisions which led directly or indirectly to the event in question (p. 15).” Later, Laffont (2008) offered a definition in the entry for “Externalities” in *The New Palgrave Dictionary of Economics*: “indirect effect of a consumption activity or a production activity on the consumption set of a consumer, the utility function of a consumer or the production function of a producer.” In microeconomics and public economics textbooks, we can find different definitions of externality as well.

In this book, we do not want to parse the cited and uncited definitions of externality, as they might be equivocal or controversial to some scholars. Instead, paraphrasing the common feature in the above definitions of externality, we may say that when some economic agents’ welfares are directly or indirectly affected by others’ activities without their explicit consent, then externality exists. Furthermore, we focus on externality phenomena in environmental problems.

It is easy to see that pollution fits all the definitions of externality described here. Pollution is generated in production or consumption, and it always affects the welfare of people in the economy other than the polluters themselves. Franklin’s 1793 legal case on

pollution is an example of an infringement of other members' welfare in the community caused by dumping waste. It provides a clear example of conflict triggered by externality. Meade (1973) uses the phrase "the control of environmental pollution and similar social costs" as the subtitle of his monograph *The Theory of Economic Externalities*. In fact, pollution is one of the most frequently used examples in textbooks to illustrate externality. By any logical inference, the theory of environmental economics and the theory of externality bond tightly. In light of this, it is no surprise that the connection between pollution control and externality is a cornerstone of environmental economics.

Pollution and the mitigation of pollution are forms of externality provisions. We can label pollution as "environmental externality," and many, if not all, environmental economics issues can be framed as environmental externality provision problems. In this monograph, we study environmental externality from a new angle, which offers a constructive approach to environmental externality through theoretical analysis and modeling, development of solution algorithms as well as numerical simulations. The research here covers various topics comprehensively and addresses a range of externality phenomena that are unique in environmental problems. We hope that such an approach provides useful tools to model and analyze various complicated environmental problems, such as climate change.

Over the past few decades, environmental economics has accumulated an abundance of literature, such that even excellent, widely-cited surveys, such as Cropper and Oates (1992), cover only limited topics in a particular time frame. More recent survey articles are restricted to a subfield or a particular topic within environmental economics. Environmental economics is a large research domain with many areas of active inquiry. Comprehensive textbooks on the subject have to be very selective in their choice of topics and cited works. In this book, we are not venturing to conduct a thorough literature survey of environmental economics. Instead, our literature review throughout the book, as an inseparable component of exposition, will be devoted to the theme of the environment and externality as well as the specific issues addressed. The purpose of literature assessments is to place our research in its proper context and to explain why we need an addition to the pool of the literature on this issue.

1.2 Why Do We Need Another Look at the Environment and Externality?

The theory of externality is one of the important research topics of public economics. In microeconomics and public economics textbooks, externality is often examined along with the theory of public goods because of their conceptual overlaps. There are comprehensive monographs and textbooks for graduate studies on the topics, such as *The Theory of Externalities, Public Goods, and Club Goods* (2nd edition) by Cornes and Sandler (1996). Several graduate-level public economics textbooks also have chapters devoted to the issues, such as chapters 1 and 2 of *Fundamentals of Public Economics* by Laffont (1988), and chapters 9 and 10 of *Public Economics* by Myles (1995). The theory of externality and public goods is also covered in advanced microeconomics textbooks, such as chapters 23 and 24 of *Microeconomic Analysis* (3rd edition) by Varian (1992) and chapter 11 of *Microeconomic Theory* by Mas-Colell, Whinston, and Green (1995). “Externality” is a high-frequency term in microeconomics and is used in analyzing various relevant economic issues. All properly-trained economists understand “externality” from different perspectives.

In microeconomic texts, for instance, externality is mainly examined from a general equilibrium perspective. The coverage includes the derivation of efficiency conditions of externality provision in the stylized setting, the introduction of the important Samuelson rule (Samuelson 1954), and the proofs of the fundamental welfare theorems of the Lindahl economy (the economy with public good or externality). The examination of externalities and public goods provides one of the applications in preference revelation mechanisms. The well-known Groves-Clarke mechanism (Clarke 1971; Groves 1973) is covered by most microeconomics textbooks (for example, Mas-Colell et al. 1995, p. 373). Nevertheless, the study of externality in public economics rarely focuses specifically on environmental problems, even though pollution, as an externality phenomenon, is used frequently in examples and in exercises. Indeed, the plethora and complexity of externality phenomena in environmental problems are not reflected thoroughly anywhere in the public economics literature.

The theory of externality has been a part of the theoretic foundation of environmental economics since the subject’s early days. *The Theory of Environmental Policy* (2nd edition) by Baumol and Oates (1988) is

an important advanced text. This book contains two parts and nineteen chapters. The first part of the book is titled “On the theory of externality,” with eight of its nine chapters devoted to the topic. It remains the most comprehensive treatment of externality theory in environmental economics texts, despite some omissions and a lack of material on some of the newest. It is this gap in the literature that has partly prompted the writing of our book. The theory of externality also receives adequate coverage in other influential and advanced texts of environmental economics. Topics directly related to “externality” comprise a chapter in *Environmental Economics*, 2nd edition by Kolstad (2011) and in *Environmental and Natural Resource Economics*, 10th edition by Tietenberg and Lewis (2014). Such coverage of externality in environmental economics texts is suitable for undergraduates.

The literature of environmental economics has expanded exponentially in the last few decades. Due to the diversity of environmental problems, the vast majority of monographs and papers in environmental economics are topically-driven and policy-oriented. Externality is rarely a thematic focus of these expositions. Without prejudice, we just present a few examples. *A Course in Environmental Economics* by Phaneuf and Requate (2017) is an up-to-date and extensive graduate textbook targeted at Ph.D. students. Its exposure of externality theory is just one out of twenty-three chapters. *Advanced Principles in Environmental Policy* by Xepapadeas (1997) is an advanced theoretical text on environmental policies. The entire analytical structure of the text only discusses externality in three sections. *Economic Theories and Global Warming* by Uzawa (2003) is a theoretic treatise of the topic and it does not treat climate change from externality provision angle. *Economics of Water Quality Protection from Nonpoint Sources: Theory and Practice*, by Ribaud et al. (1999) is a comprehensive survey report on the topic. The mere mentioning of externality is only a section heading “Nonpoint-Source Pollution is an Externality” followed by two short paragraphs.

Although “externality” is not always elaborated explicitly in individual papers in the environmental economics literature, environmental economists always recognize its ubiquity in environmental issues. Terms such as “market failure,” “tragedy of commons,” and “social costs vs. private costs” show that the essence of environmental issues are detrimental externalities caused by pollution. Correcting

inefficiency of environmental externality motivates all sorts of environmental policies, either through command and control approaches or based on market-oriented mechanisms. The close connection between environmental issues and the theory of externality is part of the professional “intuition” and “subconscious mentality” of environmental economists.

The literature of externality theory is, of course, helpful for environmental economists. However, the audience for externality theory is much wider and the implications of externality phenomena go far beyond environmental issues. The literature of externality is therefore broadly spread and this can mean that, in the minds of environmental economists, “there is a large and sometimes confusing literature on externalities” (Kolstad 2011, p. 112). The scale of the available research makes it hard to highlight the most useful and relevant topics on externality in public economics literature with an environmental economics perspective.

Baumol and Oates (1988) contains an excellent exposition of externality theory pertinent to the environmental problems. In the space of 130 pages, the book gives several propositions on the properties of externality derived in a stylized general framework. These propositions are concerned with tax tools to achieve efficiency in the presence of externalities, comparisons between quantity and price policy under uncertainties, and non-convexity of the production set caused by externality. Those results are well-known today. The expositions of the above three topics are in the spirit of Pigou (1947); Weitzman (1974); and Starrett (1972) respectively. Nevertheless, the discussions of externality in Baumol and Oates (1988) can be extended in several aspects. Firstly, externalities in the dynamic setting are absent in Baumol and Oates (1988), but many pollution situations are intrinsically dynamic. Environmental externalities in intertemporal settings possess interesting properties that static externalities do not. Besides analytical interest, these features are highly policy relevant. Secondly, the book rules out the discussion of “the small-numbers case” of polluters and deems that it lacks “importance for policy” (pp. 8–9). “Large-numbers” cases are important and wide-spread and include phenomena such as air pollution caused by car emissions, and many non-point source pollution scenarios. Nevertheless, “small-numbers” cases are important externality situations in environmental economics as well. A few significant greenhouse gas (GHG) emission nations

dominate the fate of international cooperation on climate change, and strategic situations involving a few polluters and regulators are active research areas in environmental economics today. Lastly, the diversity of various externality phenomena in environmental problems is not fully reflected in the general discussions of externality in Baumol and Oates (1988). There is also a gap between the general analysis in the book and its applications in environmental modeling. Research in environmental economics from the last two decades provides abundant examples of environmental externalities that expand the treatment of externality in Baumol and Oates (1988).

Pitfalls also exist in the application of externality theory to environmental problems. Even though the theory of externality is a part of environmental economists' training and professional intuition, well-established conclusions from the theory of externality are sometimes misinterpreted and wrongly applied in empirical studies of environmental problems. Scholars focus on the specific environmental issues in their research, while the externality characteristics of these environmental challenges are not to the fore, and are sometimes ignored. In addition, the direct linkage between the theory of externality and environmental modeling is sometimes not clear in the literature.

Assessing the treatment of the relationship between environmental problems and the theory of externality in the literature and recognizing the importance of understanding externality in environmental studies, calls for a new and comprehensive approach to address the issue. This monograph attempts to fulfill part of such a task.

In this book, we study environmental externality through a unique modeling approach. We set up two connected and unified modeling frameworks, one static and one dynamic, of environmental externality provisions. The general analytical properties of environmental externalities are derived in these frameworks, from the viewpoints of both general equilibrium and game-theoretic analysis. Through extensions and variations of these modeling frameworks, we examine various environmental issues through the perspective of externality provisions. The discussions expand upon the properties and relationships between the inefficient Cournot-Nash equilibrium and the efficient Lindahl equilibrium in the modeling frameworks. All other feasible arrangements of externality provisions (pollution mitigation), such as coalitional solutions and alternative efficient outcomes, are linked to these two benchmarks. This modeling approach highlights and

focuses on the externality characteristics of pollution; it also distinctively dichotomizes the outcomes of inefficiency and efficiency in pollution control.

In carrying out the research, we adopted a novel method that maps various efficient solution concepts of environmental externality models onto the simplex of social welfare weights of the unified models we examined. Through this approach, we established the connections between theoretic conclusions on externalities (some of them are well-known in the literature) and various model solution concepts, including the Cournot-Nash equilibrium and the Lindahl equilibrium, in a language of “geometry” with economic intuition and justification. Avoiding “confusing” and contentious debates on the nature of environmental externalities in specific contexts, we frame the examination of environmental externalities into mathematical programming problems that can be handled analytically (sometimes) and numerically (always).

In this study, we place an emphasis on identifying various solution concepts of environmental externality provision in empirical environmental models. To demonstrate the feasibility of this new methodology, we provide a constructive approach to identifying different equilibrium and strategic solution concepts related to externality provision in environmental problems. We present operational algorithms for finding various solutions and illustrate them with numerical examples. These algorithms can be used to find these solutions in most environmental modeling problems. In this book, we strive for practicability without compromising logical coherence since such approaches are beneficial methodologically to empirical problems. Structural modeling is a mainstream methodology in environmental economics and our research provides a practical tool and guidance for modeling environmental externality.

A common feature of the plethora of environmental models in this book is that they all involve environmental externalities. In this book, we analyze the properties and policy implications of these complex and colorful environmental externality phenomena, and uncover the deeply-rooted relationship between the environment and externality. Through the discussions here, one can find broad applications of the theory of externality in framing environmental problems and approaches to bridging the gap between externality theory and empirical modeling of the environment.

In sum, this monograph addresses environmental issues from an externality provision perspective. It adopts a unified modeling approach to frame environmental issues as externality provision problems and is constructed on a generic modeling framework of externality that can be readily expanded into specific pollution control problems. The book provides constructive algorithms for finding various efficient and strategic solutions related to environmental externality provision. Furthermore, it elaborates on rich applications of externality theory in environmental issues.

We aim to provide a unified treatment of the environment and externality, based on the research by the author of this monograph and numerous scholars. As mentioned above, we do not venture to conduct comprehensive surveys on the topics concerned, nor cover all aspects of environmental externality provisions. Two streams of research literature, one from the theory of externality and the other from environmental economics, merge into a vast pool of knowledge. We cannot scoop the entire pool in a single bucket. So, here we have to concede upfront that we have omitted many relevant results by many scholars in this area. As a stand-alone and self-contained exposition of a particular area, however, we hope that this book provides a unique contribution to the literature.

Useful economic theories should be helpful to empirical work and policies; meaningful theories should guide a piece of meaningful applied research. Not all theory is gray; some elegant empirical studies are “grounded theory.” This book attempts to find a balance between externality theory and environmental issues through their connections in modeling and aims to integrate theory and empirical work through modeling and numerical simulations. This approach sums up the philosophy behind the writing of the book.

1.3 Organization of This Book

In subsequent chapters, we will expand on the themes and topics outlined above. The whole volume is based around a unified modeling framework to study environmental externalities. Related content in different chapters is cross-referenced frequently and special effort has been made to keep the symbols and notations as simple as possible and consistent throughout. To facilitate smooth reading, proofs of propositions and other analytical results follow the proposition statements.

The algorithms for finding various solution concepts of the models are explained in the main text, while the programming code for these algorithms, illustrated through numerical examples, is included in chapter appendices.

In Chapter 2, we first discuss the denotation and connotation of environmental externality before introducing the basic models of environmental externality provision in the static and the dynamic settings. The models in static setting are called Static Environmental Externality (Efficiency) model, or SEEE model, and Static Environmental Externality (Nash) model, or SEEN model. The models in dynamic setting are called Dynamic Environmental Externality (Efficiency) model, or DEEE model, and Dynamic Environmental Externality (Nash) model, or DEEN model. The structure and assumptions of these models are also explained. The extensions of these models cover a broad range of environmental externalities in real life. The stylized and generic models described in this chapter are the modeling framework of subsequent analysis and elaborations.

Chapter 3 is a comprehensive analysis of the basic models from a general equilibrium perspective. Various efficient solution concepts of the models are introduced and analyzed in this chapter. These include the core, the Lindahl equilibrium without transfers, the Nash bargaining solution, as well as the Benthamite and the Negishi solutions of the model. Propositions related to these solution concepts are also proven here. In addition, the chapter presents analytical results related to the Lindahl equilibrium and the Nash bargaining solution that represent pioneering work in the field. The algorithms and numerical examples for solving those efficient solution concepts are also provided and explained.

Chapter 4 examines the models of environmental externality presented in Chapter 2 from a game-theoretic perspective. Within the same modeling framework, we construct the noncooperative Cournot-Nash game, the cooperative bargaining game, and coalitional games of environmental externality provision. Efficient solution concepts of the models in Chapter 3 are re-examined from the strategic perspective. In addition, algorithms and numerical examples for searching and identifying the game-theoretic solutions of the basic models are provided.

Chapter 5 extends the analysis to explore externality phenomena in environmental issues that are beyond the basic models in Chapter 2. The assumptions and structure of models in this chapter are more

complicated than the basic models in Chapter 2 and demonstrate richness in the relationship between the environment and externality. These extended models include “correlated externality,” “mixed externality,” increasing returns to scale (IRS) in environmental externality generation, and environmental externalities in the exhaustible resource models. The analytical properties and algorithm issues for solving these models are provided.

In Chapter 6, we apply the models of environmental externality developed in previous chapters to empirical environmental issues related to climate change and other pollution problems. We identify and calculate the Lindahl tax that enables the Lindahl equilibrium outcome in market setting. We also examine other second-best tax regimes. We extend the basic modeling framework developed in this study into integrated assessment model – the core methodology in economics of climate change, through digesting the famous RICE model. We also use the coalitional game discussed in Chapter 4 to study international environmental agreements (IEA) issues that is closely connected with climate negotiations. Finally, we analyze some local air and water pollution models as environmental externality provision problems.

In the Epilogue, we summarize our main results, reassess the analytical framework in the context of environmental economics literature, and indicate future research topics related to the environment and externality.