

Charles W. Howe

NATURAL
RESOURCE
ECONOMICS

Issues, Analysis, and Policy

NATURAL RESOURCE ECONOMICS

Issues, Analysis, and Policy

CHARLES W. HOWE

Department of Economics
University of Colorado

JOHN WILEY & SONS

New York · Chichester · Brisbane · Toronto

Copyright © 1979, by John Wiley & Sons, Inc.

All rights reserved. Published simultaneously in Canada.

Reproduction or translation of any part of this work beyond that permitted by Sections 107 and 108 of the 1976 United States Copyright Act without the permission of the copyright owner is unlawful. Requests for permission or further information should be addressed to the Permissions Department, John Wiley & Sons, Inc.

Library of Congress Cataloging in Publication Data:

Howe, Charles W

Natural resource economics.

Bibliography: p.

Includes index.

1. Natural resources. I. Title.

HC55.H69 333 78-24174

ISBN 0-471-04527-6

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

Preface

Natural resources have attracted increasing attention in the 1970s as energy, food, water, and other resources have undergone a sequence of crises. There is greatly heightened concern about national and world capacities for producing sufficient reproducible resource commodities (e.g., products of agriculture, forestry, and water), and perhaps even greater concern over the implications of world and national dependence on finite stocks of nonrenewable resources (e.g., the fossil fuels and nonfuel minerals). These issues of resource availability have been associated more and more with environmental problems resulting from expanded energy use, the exploitation of more diffuse resources, deforestation, and certain agricultural practices. The accumulation of pollutants in the atmosphere, the soils, and in water bodies has become a global phenomenon, no longer limited to local or regional settings.

This book integrates the field of natural resource economics for the first time, exhibiting the common structure of many of the prominent natural resource management problems, whether they relate to renewable or nonrenewable resources, at the economywide level or within particular natural resource sectors. Throughout the book, the theoretical formulation of problems and the use of the tools of economic analysis to analyze those problems are accompanied by historical and contemporary real-world illustrations. Several extended case studies are included, and the policy implications of the analyses are clearly drawn. In accomplishing these objectives, the book utilizes the most up-to-date theoretical and empirical research results, not only from economics but from geology, hydrology, and the environmental sciences. This book seeks to establish this broader context within which natural resource issues can be understood and evaluated.

Markets continue to play important roles in the development and allocation over time of natural resources, both nationally and internationally. Therefore, an understanding of the functioning of markets and their strengths and weaknesses is important. These markets, along with

government agencies, produce data from which we must infer the evolving natural resources situation and its implications for human welfare. Are resources growing scarcer? Is this important? Will past solutions continue to work? A data base of the available evidence on these issues is presented and analyzed.

The analytical framework first applied to macroeconomic growth is specialized to the analysis of the particular resource scarcity situations in several key natural resources sectors: energy, nonenergy minerals, forestry, fisheries, water resources, and preserved natural environments. The problems and policy issues of these sectors are described and analyzed in a dynamic management context.

The book concludes with a review of the factors that will be critical to our future natural resources situation, and seeks to derive from the earlier analysis a set of guidelines for the formulation of what is called a "responsible natural resources policy" that emphasizes intergenerational equity.

This book is intended for upper-division undergraduates and graduate students taking a first course in natural resource economics. Typical undergraduate economics majors with principles, intermediate theory, and quantitative methods courses behind them are ideally prepared to use these materials, but students from many disciplines with principles of economics and college mathematics will be sufficiently prepared. The course will attract students from geography, geology, political science, engineering, agriculture, ecology, forestry, and conservation. Masters candidates from these disciplines often take the course, especially when it can be applied toward graduate credit.

The book provides a full semester's work without outside supplementation. The bibliography provides a highly *selected* list of readings that can be used by the instructor to add emphasis to particular areas, but this is not at all necessary. The mode of presentation alternates among verbal exposition, graphical analysis, and simple mathematical models. Whenever mathematical tools are used, clear verbal summaries of results are provided for the nonmathematical reader. While a particular mathematical tool (e.g., the selective use of results from optional control theory) may be thought of as "advanced math," the application of a single basic theorem often permits the quick derivation of important results that would otherwise have to be derived through tedious, notationally burdensome approaches.

St. Paul
May 1978

Charles W. Howe

Acknowledgments

Had it not been for a sabbatical leave, publication of this book would have been much delayed, so I thank the Department of Economics of the University of Colorado for granting the leave and the Department of Agricultural and Applied Economics of the University of Minnesota for providing an appointment as Hill Visiting Professor.

Among the many persons who have generously assisted the author, several have been particularly helpful. Dwight R. Lee, of the University of Colorado, shared with the author for several years the teaching of the basic course in natural resource economics at the University of Colorado, which led to the idea of this book. This collaboration has been a rich experience for me. V. Kerry Smith, of Resources for the Future, Inc., provided extensive and penetrating critiques of several versions of the manuscript, always suggesting alternative approaches and valuable literature (much of it his own writing) bearing on the subject. The entire undertaking would have been much more modest without this input. Lee R. Martin, of the Department of Agricultural and Applied Economics, University of Minnesota, generously read and reread several versions of the core chapters, always insisting on clarity of exposition and greater generality of the analytical framework. It was through extended conversations with him that much of the unity of the natural resources field became clear to me. Anthony C. Fisher, of Resources for the Future, Inc. and the University of California, Berkeley, provided many of the insights on which this book was constructed. His seminal paper "On Measures of Natural Resource Scarcity" (1979) profoundly affected the approach taken in this book.

Others who have been of great assistance are Harold J. Barnett of Washington University, whose earlier work constitutes a major building stone of current resource economics and who gave guidance to an early draft; Daniel W. Bromley, of the University of Wisconsin, who critiqued earlier outlines and pointed to important omissions (some of which remain); Gardner Brown, of the University of Washington, and Barry C.

Field, of the University of Miami, whose joint work on indicators of scarcity contributed greatly to this book; Emery N. Castle, of Resources for the Future, Inc., who reviewed one draft; Marion Clawson, of Resources for the Future, Inc., who has shown many how to do effective applied research and who taught the author a lot about forestry; Ronald G. Cummings, of the University of New Mexico, whose exuberance over natural resource economics has been a stimulus to the author for a long time; K. William Easter, of the University of Minnesota, who coauthored an earlier book and provided stimulating discussions during this leave period; Robert H. Haveman, of the University of Wisconsin, with whom many beneficial discussions have been held; John V. Krutilla, of Resources for the Future, Inc., whose pioneering research in water and natural environments opened those important areas to economics; Richard B. Norgaard, of the University of California, Berkeley, who critiqued the first draft; Clifford S. Russell, of Resources for the Future, Inc., who provided detailed critique of the earlier chapters; Vernon W. Ruttan, of Minnesota, who demonstrated the importance of induced innovation to the author; and Anthony Scott, of the University of British Columbia, who provided many excellent suggestions for broadening the treatment to include institutional issues. John S. Howe, currently a graduate student at Purdue University, sought out much of the data presented in the book and acted as a student soundingboard for many of the ideas. Frederick H. Bell and Manuel H. Johnson, Jr., of Florida State University, provided their updated series of the Barnett and Morse data base. P. J. Wilkinson, former economics editor with John Wiley and Sons, Inc., was extremely helpful in the task of defining the audience to which the book should be directed and in keeping me in that track.

Not at all the least of the help was that of Frances Macy, in the Department of Economics at Colorado, who was of tremendous assistance in many ways but, of particular relevance, helped protect some of my time over the several years when the book was being conceived. She also typed part of the first draft. Linda L. Schwartz, of the Department of Agricultural and Applied Economics at Minnesota, completed the typing of the first draft and typed the entire final draft, in good humor and in keeping with the deadlines, and all for a visitor. To her, many thanks.

C.W.H.

Table of Contents

<i>List of Figures</i>	xvii
<i>List of Tables</i>	xxv
1. Overview of the Natural Resources Field	1
1.1. Characteristics and Definitions	1
1.2. Major Natural Resource Issues	3
1.3. Historical Background	6
1.4. Reserves, Rates of Use, and Exploration	7
1.5. Scarcity of Resources	10
1.6. Factors Mitigating Scarcity	11
1.7. The Long-Term Outlook	13
1.8. The Role of Economics in Natural Resources Policy Formulation and Management	14
2. Natural Resource Commodity Production and <i>in Situ</i> Stocks: A Conceptual Framework and Empirical Survey	16
2.1. A Basic Model of Natural Resources Use	17
2.2. The Nature of Natural Resource Stocks	19
2.3. Motivations for Holding Reserves	24
2.4. Interpreting Reserve-to-Use Ratios	25
2.5. The Historical and Current Natural Resource Situation in the United States	27
3. Natural Resources Concern Is Not New	44
3.1. Historical Episodes of Natural Resources Concern	44

3.2.	Natural Resources in Classical Economic Thought	49
3.3.	The American Conservation Movement and Related Issues	52
3.4.	U.S. Government Agencies and Programs Involved in Natural Resources Management	58
4.	The Impacts of Natural Resource Availability on Economic Growth: Forms and Effects of Scarcity	61
4.1.	A Model of Frontier and Simple Ricardian Economies	62
4.2.	Special Examples of the Frontier and Simple Ricardian Economies	65
4.3.	A Malthusian Special Case	68
4.4.	A Simple Ricardian Economy With Technological Change	69
4.5.	Natural Resource Stock Effects and the Concept of User Cost	71
4.6.	Stock Effects, User Cost, and Rents on <i>in situ</i> Natural Resources	75
4.7.	A Generalized Model of User Cost and Scarcity Rents	79
4.8.	Further Analysis of Economic Growth Potential Under a Fixed Supply of Natural Resources	82
4.9.	Summary	87
5.	Optimal Resource Use Over Time and Likely Market Behavior	89
5.1.	A Basic Model of Optimum Natural Resource Use Over Time	90
5.2.	The Pattern of Natural Resource Use Over Time Under a Competitive Market Structure	94
5.3.	The Pattern of Natural Resource Use Under a Monopolistic Market Structure	97
5.4.	Market Adjustment Processes	98
5.5.	The Stability of Natural Resource Market Adjustment Processes	101

5.6.	A Review of Reasons for Market Failure to Achieve Optimum Patterns of Resource Use Over Time	103
5.7.	Summary	107
6.	Empirical Indicators of Evolving Natural Resources Scarcity	108
6.1.	Further Observations on Prices as Indicators of Natural Resources Scarcity	111
6.2.	Relative Price Evidence	114
6.3.	Scarcity Rents: Prices of <i>in situ</i> Resources	118
6.4.	Unit Costs of Natural Resource Commodity Production	119
6.5.	Evidence on Elasticities of Substitution of Other Inputs for Natural Resources	121
6.6.	The Commission on Population Growth and the American Future: Population, Resources, and Environment	127
6.7.	Summary of the Evidence	127
7.	Factors Mitigating Natural Resources Scarcity	129
7.1.	The Salvation of Telluride: An Example of the Process of Adaptation	129
7.2.	Technological Innovation	130
7.3.	The Process of Natural Resource Discovery and Related Technological Changes	132
7.4.	Technological Changes Increasing the Efficiency of Resource Recovery	134
7.5.	Technological Changes Facilitating Substitutions in Production Processes Away from Scarce Resources	135
7.6.	Scale Economies	137
7.7.	Facilitating Substitutions in Consumption	139
7.8.	Improved Transportation and Trade	139
7.9.	Recycling	140
7.10.	Do We "Waste" Natural Resources?	144
7.11.	Will Mitigating Forces Continue in the Future?	147

8. Intertemporal Comparisons of Well-being: Efficiency, Equity, and Risk	149
8.1. Criteria for Intertemporal Decision Making: Pareto Efficiency	151
8.2. The Determination of "Present Values" of Benefits and Costs through Discounting	152
8.3. The "Social Time Preference" Approach to Discounting	155
8.4. What Discounting Does <i>Not</i> Do	158
8.5. Considerations of Risk and Uncertainty in Natural Resources Planning and Management	160
8.6. Alternatives to the Intertemporal Discounting Type of Criterion for Natural Resources Planning	165
9. The Management of Energy Resources	169
9.1. Factors Leading to the 1973 Energy Crisis	170
9.2. An Economic Analysis of the Energy Crisis	173
9.3. Aftermath of the Energy Crisis	177
9.4. International Comparison of Energy Use	181
9.5. The Outlook for New Supplies of Energy Commodities	186
9.6. Nuclear Power: The Great Dilemma	196
10. Mineral Availability and Exploration	203
10.1. Physical Characteristics of Mineral Resource Availability	203
10.2. The Effects of Exploration on the Socially Optimal Paths of Natural Resource Use, Price, and <i>in situ</i> Rents	208
10.3. Dealing with the Risks of Exploration and Development from the Mining Firm's Viewpoint: Baysean Decision Strategies	212
10.4. Exploration and Discovery from Society's Viewpoint	218
10.5. Summary and Outlook	219

11. The Economics of Forest Management	221
11.1. Background of U.S. Forestry	221
11.2. Timber Harvesting Practices: The Optimum Rotation	225
11.3. The Optimum Rotation: Mathematical Derivation	228
11.4. Sensitivity Analysis of the Optimum Rotation	230
11.5. Multiple-Use Forestry Management	232
11.6. Some Traditional Concepts in Forest Management	235
11.7. Unanswered Questions and Future Developments	237
12. Common Property Resources: Theory and Examples	241
12.1. The Analytics of the Static Common Property Problem	243
12.2. Congestion of Facilities as a Case of Common Property Resource Management	245
12.3. Environmental Pollution as a Case of Common Property Resource Management	248
12.4. Policy Tools for Improving the Management of Common Property Resources	249
12.5. More on Congestion in Natural Resource Systems	252
13. The Management of Fisheries: A Case of Renewable but Destructible Common Property Resources	256
13.1. Basic Biological Relationships	258
13.2. An Example of a Static Fisheries Management Model	261
13.3. Optimum Fisheries Management Over Time	263
13.4. The Dynamic Behavior of a Competitively Exploited Fishery	267
13.5. Regulation Alternatives for Fisheries Management	270
13.6. Summary	274

14. Water Resource Systems	276
14.1. Characteristics of Water Resource Systems	276
14.2. The Nature of Water System Developments	282
14.3. The Colorado River: A Brief Case Study	291
14.4. Economic Aspects of Groundwater Management	295
14.5. Water Quality Management	302
14.6. Minimum Cost of Meeting Standards	307
14.7. Two Case Studies of Water Quality Management	308
14.8. Some Characteristics of the Demand for Water	311
15. Natural Areas and Ecosystems as Natural Resources	316
15.1. Economic Aspects of Unique Natural Areas	318
15.2. Measuring the Demand for Outdoor Recreation	321
15.3. A Suggested Benefit-Cost Exercise in Comparing Development with Preservation	327
15.4. Closing Observations on the Natural Environment as Amenity and Constraint	328
16. Elements of a Responsible Natural Resources Policy	330
16.1. Definition of a Responsible Natural Resources Policy	331
16.2. A Review of Critical Factors Conditioning Future Natural Resource Availability	332
16.3. Guidelines for a Responsible Natural Resources Policy	335
16.4. Necessary Conditions for a Responsible Decision-making Process	337
Bibliography	340
Index	345

Figures

2.1	U.S. Bureau of Mines/U.S. Geological Survey mineral and coal resource and reserve categories	21
2.2	Availability diagram for uranium (expressed as U_3O_8)	23
2.3	U.S. population, 1900–1980; consumption of raw materials, 1900–1969	27
2.4	Resource sectors: per capita consumption	28
2.5	Mineral sectors: per capita consumption	29
2.6	Production of raw materials in the United States: 1960–1969	30
2.7	Annual visits to various types of recreation areas, 1920–1976	31
2.8	Employment and output: resource industries as percent of all industries	32
2.9	Estimated labor requirements: total agriculture and agricultural sectors (at five-year intervals)	33
2.10	Employment: total mining and mining sectors (at five-year intervals)	33
2.11	Resources, manufacturing, gross national product: employment/output	34
2.12	Resource sectors: employment/output	34

2.13	Price indexes for raw materials, finished commodities, and all wholesale commodities in the United States: 1900-1969	35
2.14	All extractive: net trade as percent of consumption (1954 prices—gold and silver excluded)	42
2.15	Agriculture: net trade as percent of consumption	42
2.16	Net trade: all minerals except gold and silver	42
2.17	Mineral fuels: net imports (five-year averages)	43
3.1	Depletion history of Lake Superior district iron ore, showing overlapping stages of depletion of a mining region	47
3.2	Ricardian increasing costs	51
4.1	Input transformation curves, GNP isoquants, and the optimum expansion path of a simple Ricardian economy	64
4.2	Growth in a frontier economy	65
4.3	Growth of GNP in a malthusian economy with a fixed limit on the input of R_0	68
4.4	Hypothetical costs of exploiting two deposits	77
4.5	The short-run supply curve	77
4.6	The time paths of the rent on <i>in situ</i> resources and optimum resource use	81
5.1	Characterization of the optimal rate of natural resource commodity production at each instant t	93
5.2	Paths of socially optimum and competitively determined natural resource commodity production and <i>in situ</i> stocks	96

5.3	Paths of natural resource commodity price and <i>in situ</i> scarcity rents along the socially optimum and competitive paths	96
5.4	Initial monopolistic and competitive production rates and prices for given $q(0)$ and $S(0)$	98
5.5	A simple depiction of the natural resources commodity market and the <i>in situ</i> resources market	99
5.6	The imposition of an effective price ceiling	105
5.7	Unregulated and regulated results with constant <i>MC</i> : an example	106
6.1	Douglas fir stumpage price relative to Douglas fir lumber price	113
6.2	Production and price history of mercury in the United States	114
6.3a	Forestry products	116
6.3b	Agricultural products	116
6.3c	Metals	116
6.3d	Fuels	116
6.4	Differing degrees of substitutability between labor-capital and natural resources	122
7.1	Average cost curves, Model A	138
7.2	Optimal reuse ratio for paper residuals in the production of newsprint	141
8.1	Net benefit streams of three alternative policy changes or projects	153

8.2	Typical time pattern of construction costs, site opportunity costs, and benefits from a water project	159
9.1	The postwar energy market	174
9.2	The market for gasoline in 1973–1974	176
9.3	Energy intensiveness for the United States	178
9.4	The 1967 energy intensiveness of consumer goods and services	179
9.5	The 1967 energy intensiveness of capital investments	180
9.6	The energy/GNP ratio for several countries over time, with hydroelectric power counted at 3 kwht/kwhe	182
9.7	1973 per capita energy consumption rate versus per capita GNP	183
9.8	Past estimates and future projections of world ultimate oil reserves	188
9.9	Global proved reserves at year end—annual and cumulative crude oil production (MMbbls)	189
9.10	Reserves proved annually in United States, world (MMbbls)	190
9.11	Potential oil-bearing areas and worldwide concentration of oil drilling	191
9.12	History of exploratory drilling and discoveries of \$8 per pound U_3O_8	197
9.13	Discovery rate compared to cumulative exploration	198