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A COURSE IN ENVIRONMENTAL ECONOMICS

Theory, Policy, and Practice

This unique graduate textbook offers a compelling narrative of the growing field of environmental economics that integrates theory, policy, and empirical topics. Authors Daniel J. Phaneuf and Till Requate present both traditional and emerging perspectives, incorporating cutting-edge research in a way that allows students to easily identify connections and common themes. Their comprehensive approach gives instructors the flexibility to cover a range of topics, including important issues – such as tax interaction, environmental liability rules, modern treatments of incomplete information, technology adoption and innovation, and international environmental problems – that are not discussed in other graduate-level texts. Numerous data-based examples and end-of-chapter exercises show students how theoretical and applied research findings are complementary, and will enable them to develop skills and interests in all areas of the field. Additional data sets and exercises can be accessed online, providing ample opportunity for practice.

Daniel J. Phaneuf is Professor of Agricultural and Applied Economics at the University of Wisconsin-Madison. He has been Managing Editor of the *Journal of Environmental Economics and Management*, and is currently Editor in Chief of the *Journal of the Association of Environmental and Resource Economists*. He is a member of the US Environmental Protection Agency Science Advisory Board and also serves on the board of directors for the Association of Environmental and Resource Economists. His many research articles have appeared in top field and general economics outlets, and he has won awards for his graduate and undergraduate teaching in environmental economics and econometrics.

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Theory, Policy, and Practice

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For Tammo, Finja, and Silke – D.P.
For Sabine and Frederik – T.R.

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Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

Contents

Figures *page* xviii
Tables xxi
Preface xxiii
Notational Conventions xxviii

PART I ECONOMICS AND THE ENVIRONMENT

1 Environmental Economics and the Theory of Externalities **3**
1.1 Market Failures 4
1.2 Descriptive Explanation of Market Failure 6
1.3 A Formal Model of Externalities 7
1.3.1 Pareto Optimality 8
1.3.2 The Competitive Market 9
1.3.3 Market Intervention 11
1.4 Points Going Forward 12
1.5 Summary 14
1.6 Further Reading 15
Exercises 15

2 Environmental Problems and Policy Issues **17**
2.1 Evolution of Environmental Policy and Economics 17
2.2 Major Pollutants and Pollution Problems 21
2.2.1 Water Pollution 21
2.2.2 Air Pollution 23
2.2.3 Land Pollution 26
2.2.4 Pollution Problems and Economics 27
2.3 Economics and Ecology 28
2.4 Policy Examples 29
2.4.1 Sulfur Dioxide 29
2.4.2 Nutrient Surface Water Pollution in the US 30
2.4.3 Hazardous Waste in the US 31
2.4.4 Climate 32

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Cambridge University Press
978-1-107-00417-7 — A Course in Environmental Economics
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

2.5 Summary 34
2.6 Further Reading 34

3 Introduction to the Theory of Environmental Policy 35
3.1 A Simple Model of Damages and Costs 35
3.1.1 Damage Function 36
3.1.2 Abatement Costs 36
3.1.3 Efficient Allocation 37
3.2 Property Rights and the Coase Theorem 39
3.2.1 Household Ownership of Pollution Rights 39
3.2.2 Firm Ownership of Pollution Rights 40
3.2.3 Coase Theorem 40
3.2.4 Comments on the Polluter Pays Principle 41
3.3 Environmental Policy Instruments 44
3.3.1 Command and Control 44
3.3.2 Emission Taxes 46
3.3.3 Auctioned Pollution Permits 48
3.3.4 Freely Distributed Transferable Permits 49
3.3.5 Subsidies 52
3.4 Aggregate Marginal Abatement Cost Curve 53
3.5 Summary 54
3.6 Further Reading 55
Exercises 56

PART II THE DESIGN OF ENVIRONMENTAL POLICY

4 Imperfect Information 61
4.1 Price Versus Quantities 62
4.1.1 Damage Function Uncertainty 62
4.1.2 Abatement Cost Function Uncertainty 63
4.1.3 Weitzman Theorem 65
4.1.4 Contemporary Policy and Research Relevance 69
4.2 Hybrid Policies 70
4.2.1 Safety Valves 70
4.2.2 Approximating the Marginal Damage Curve 73
4.3 Mechanism Design 75
4.3.1 Kwerel's Mechanism 76
4.3.2 Montero's Mechanism 77
4.3.3 Second-Best Mechanism Design 82
4.4 Summary 86
4.5 Further Reading 87
Appendix A: Derivation of Weitzman Theorem Result 88
Appendix B: Characterization of Optimal Second-Best Solution 90
Exercises 90

5 Competitive Output Markets 94
5.1 Model Extension 95
5.1.1 Cost Functions 95

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CAMBRIDGE

Cambridge University Press
978-1-107-00417-7 — A Course in Environmental Economics
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

5.1.2 Market Demand 97
5.1.3 Welfare and Social Optimum 99
5.2 Environmental Policy Instruments 100
5.2.1 Taxes 101
5.2.2 Permits and Other Instruments 104
5.3 Standards Reconsidered 108
5.4 Long Run Optimality of Environmental Policy Instruments 111
5.4.1 Long Run Social Optimum 111
5.4.2 Standards 112
5.4.3 Taxes 113
5.4.4 Auctioned and Freely Distributed Permits 114
5.4.5 Subsidies 115
5.5 An Expanded Examination of Abatement Costs 116
5.6 Summary 119
5.7 Further Reading 120
Appendix: Proof of Proposition 5.3 120
Exercises 121

6 Non-Competitive Output Markets 124
6.1 Monopoly 125
6.1.1 Taxation When Abatement is Not Possible 125
6.1.2 Taxation When Abatement is Possible 128
6.1.3 Regulating Output and Emissions Simultaneously 130
6.2 Oligopolies 131
6.2.1 Firm Behavior Under Emission Taxes in a Cournot Model 131
6.2.2 Regulator's Problem Under Cournot Oligopoly 133
6.2.3 Entry and Exit 135
6.3 Extensions 137
6.4 Summary 138
6.5 Further Reading 139
Exercises 139

7 Environmental Policy with Pre-existing Distortions 142
7.1 Extending the Model 143
7.1.1 Optimum with No Labor Market Distortion 145
7.1.2 A Labor Market Distortion 146
7.2 Second-Best Optimal Pollution Levels 148
7.2.1 Non-revenue Raising Environmental Policy 148
7.2.2 Revenue Raising Environmental Policy 154
7.2.3 Prospects for a Double Dividend? 159
7.2.4 Second-Best Optimal Pollution 160
7.3 An Extended Example 161
7.3.1 Setting an Environmental Standard 162
7.3.2 Setting an Emission Tax 163
7.3.3 A Numerical Example 164
7.4 Policy Instruments 165

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CAMBRIDGE

Cambridge University Press
978-1-107-00417-7 — A Course in Environmental Economics
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

		7.4.1 Taxes and Auctioned Permits	165
		7.4.2 Freely Distributed Permits and Command and Control	166
		7.4.3 Subsidies	167
	7.5	Generalizations and Empirical Evidence	167
		7.5.1 A Generalization	167
		7.5.2 Empirical Research and Policy Implications	169
	7.6	Summary	170
	7.7	Further Reading	171
		Exercises	172
8		**Institutional Topics in Cap and Trade Programs**	**175**
	8.1	The Spatial Dimension	176
		8.1.1 A Spatial Pollution Model	176
		8.1.2 Decentralization	177
	8.2	The Temporal Dimension	178
		8.2.1 A Two-Period Model	179
		8.2.2 Should Banking Be Allowed?	180
	8.3	Market Power	182
	8.4	Transaction Costs	187
		8.4.1 Modeling Transaction Costs	187
	8.5	Initial Allocation Schemes	191
		8.5.1 Closed Trading Systems	192
		8.5.2 Open Trading Systems	195
	8.6	Overlapping Regulations	196
		8.6.1 Permit Trading and Emission Taxes	196
		8.6.2 Emission Trading and Emission Policies	197
	8.7	Monitoring and Compliance	198
		8.7.1 A Simple Model with Monitoring and Punishment	198
		8.7.2 Incremental Punishment and Costly Monitoring	199
		8.7.3 Second-Best Optimal Inspection Policy with Costly Inspection	200
		8.7.4 Compliance and Monitoring Under Cap and Trade	201
	8.8	Summary	203
	8.9	Further Reading	205
		Appendix: An Example of Beneficial and Harmful Banking	205
		Exercises	207
9		**Ambient Pollution Control**	**212**
	9.1	Deterministic Non-point Source Pollution	213
	9.2	Stochastic Ambient Pollution	215
		9.2.1 The Constrained Social Optimum	216
		9.2.2 Decentralization of the Social Optimum	219
		9.2.3 Uniform Tax	222
		9.2.4 When Firms Can Observe their Idiosyncratic Shocks	223
		9.2.5 When Firms Have Several Choices	224
		9.2.6 Non-linear Tax Scheme	224
	9.3	Other Approaches	225

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CAMBRIDGE

Cambridge University Press
978-1-107-00417-7 — A Course in Environmental Economics
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

9.4 Policy and Experimental Evidence 226
9.5 Summary 228
9.6 Further Reading 229
Appendix A: Second-Best Optimal Firm-Specific Taxes with Multiple Inputs 229
Appendix B: Derivation of (9.39) 231
Exercises 231

10 Liability 234
10.1 Basic Model 235
10.2 Liability Rules for a Solvent Firm 238
10.2.1 Strict Liability 238
10.2.2 Negligence Rule 239
10.3 Liability Rules for a Judgment-Proof Firm 240
10.3.1 Strict Liability 241
10.3.2 Negligence Rule 243
10.4 Liability Rules If Insurance is Available 244
10.4.1 Risk Neutrality 245
10.4.2 Risk Aversion 246
10.4.3 Compulsory Insurance 251
10.4.4 Lender Liability 253
10.5 Alternative Causality 254
10.5.1 Model Extension 254
10.5.2 Proportional Liability 255
10.5.3 Collective Liability 256
10.5.4 Costly Monitoring 256
10.6 Multi-causality 257
10.7 Examples of Environmental Liability Laws 258
10.8 Summary 260
10.9 Further Reading 261
Appendix A: Proof of Proposition 10.5 262
Appendix B: Proof of Proposition 10.6 262
Appendix C: Proof of Proposition 10.7 263
Exercises 264

11 Innovation and Adoption of New Technology 267
11.1 The Private Innovation Model 268
11.1.1 Decentralized Decisions 269
11.2 Investment Spillovers 270
11.2.1 Second-Best Optimal Environmental Policy 271
11.3 Discrete Adoption Decisions 272
11.3.1 Additional Model Features 272
11.3.2 Adoption Incentives Under Different Policy Instruments 274
11.3.3 Ranking of Policy Instruments 279
11.3.4 The Socially Optimal Degree of Technology Adoption 282
11.3.5 Decentralization of Optimal Solution 285
11.4 Environmental R&D and Licensing 288

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CAMBRIDGE

Cambridge University Press
978-1-107-00417-7 — A Course in Environmental Economics
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

11.4.1 Value of a General Process Innovation 289
11.4.2 A Model of R&D 290
11.4.3 A Model of Environmental Innovation 291
11.5 A Comprehensive Model of R&D and Technology Adoption 293
11.5.1 Socially Optimal Allocation 294
11.5.2 Decentralized Decision-Making and First-Best Regulation 295
11.5.3 Second-Best Analysis: Environmental Policy Only 297
11.6 Experimental evidence 303
11.7 Summary 304
11.8 Further Reading 306
Appendix A: Derivation of (11.92) 307
Appendix B: Ex Ante Regulation After R&D and Technology Pricing 307
Appendix C: Simultaneous Decisions on the Tax Rate and Technology Price 309
Appendix D: Derivation of (11.101) 310
Exercises 310

12 International Environmental Problems 313
12.1 Transboundary Pollution in an Autarky Model 315
12.1.1 Model 315
12.1.2 Non-cooperative Behavior 316
12.1.3 Cooperative Behavior 316
12.2 Commodity Transfer 318
12.3 Multiple Commodities and Proper Trade 321
12.3.1 Model Extension 322
12.3.2 Efficient Allocation 322
12.3.3 Unilateral Environmental Policy in a Small Open Economy 324
12.4 Large Open Economies 325
12.4.1 Optimal Unilateral Policy with a Foreign Emission Tax 326
12.4.2 Optimal Unilateral Policy with a Foreign Emission Standard 330
12.4.3 Internationally Mobile Factors 332
12.4.4 Separation of Instruments 332
12.5 Imperfect Competition and Environmental Dumping 333
12.5.1 Extension of the Basic Model to Imperfect Competition 334
12.6 Interactions with Energy Markets 336
12.6.1 Model Adjustments 336
12.6.2 Spatial Leakage 337
12.6.3 Intertemporal Leakage and the Green Paradox 338
12.7 International Coalition Formation 340
12.8 Kyoto Mechanisms: JI and CDM 341
12.9 Does Trade Liberalization Induce More or Less Pollution? 344
12.9.1 A Stylized Ricardian Model 344
12.10 Summary 347
12.11 Further Reading 348

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CAMBRIDGE

Cambridge University Press
978-1-107-00417-7 — A Course in Environmental Economics
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

Appendix: Proof of Proposition 12.2 349
Exercises 351

13 Accumulating Pollutants 353
13.1 The Accumulating Pollutant Cost-Damage Model 354
13.1.1 Stock Dynamics 354
13.1.2 Abatement Cost and Damage 354
13.2 Dynamic Optimality 355
13.2.1 Discrete Time 355
13.2.2 Continuous Time 357
13.2.3 The Steady State 358
13.2.4 Optimal Path to the Steady State 360
13.2.5 Phase Diagrams 361
13.2.6 Policy Instruments and Decentralized Decision-Making 367
13.2.7 Final Remarks 368
13.3 Exhaustible Resources and Pollution Control 368
13.3.1 Pure Resource Extraction Model 369
13.3.2 Optimal Extraction of a Polluting Resource 371
13.4 Summary 375
13.5 Further Reading 376
Appendix A: Introduction to the Calculus of Optimal Control 376
Appendix B: Linear Marginal Damage and Marginal Abatement Cost Curves 379
Appendix C: Proof of Proposition 13.1 381
Exercises 386

PART III VALUING THE ENVIRONMENT
14 Theory of Applied Welfare Analysis 391
14.1 General Setup 392
14.2 Price Change Welfare Measures 394
14.2.1 Compensating and Equivalent Variation 394
14.2.2 Consumer Surplus 398
14.2.3 Towards Measurement 402
14.3 Quantity Change Welfare Measures 405
14.3.1 Compensating and Equivalent Variation 406
14.3.2 The Fundamental Challenge of Measurement 409
14.4 WTP and WTA 410
14.5 Welfare Analysis Under Uncertainty 413
14.6 Summary 416
14.7 Further Reading 417
Exercises 418

15 Revealed Preference Models 420
15.1 The Fundamental Challenge Revisited 421
15.1.1 A Direct Approach 422
15.1.2 An Indirect Approach 423
15.1.3 Why Revealed Preference? 424

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Cambridge University Press
978-1-107-00417-7 — A Course in Environmental Economics
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

15.2 Complements 425
15.2.1 Ordinary Demand Functions 427
15.2.2 Specifying Ordinary Demand Equations 431
15.2.3 Application Preview 434
15.3 Substitutes 434
15.3.1 Technology and Behavior 435
15.3.2 Exact Welfare Measures 438
15.3.3 Bounding Results 440
15.3.4 Application Preview 441
15.4 Quality-Differentiated Market Goods 442
15.4.1 Hedonic Model 443
15.4.2 Application Preview 448
15.5 Summary 449
15.6 Further Reading 450
Appendix A: Proof of Proposition 15.2 450
Appendix B: Proof of Proposition 15.3 453
Appendix C: Proof of Proposition 15.4 454
Exercises 455

16 Discrete Choice Models 457
16.1 Conceptual Basis 458
16.1.1 Theoretical Discrete Choice Model 458
16.1.2 Towards an Empirical Model 460
16.1.3 A Running Example 461
16.2 Basic Econometrics 462
16.2.1 Conditional Logit Model 463
16.2.2 Specification 464
16.3 Identification 468
16.4 Features of the Logit Model 472
16.5 Advanced Econometrics 473
16.6 Welfare Computation 477
16.6.1 The Linear in Parameters Logit Model 477
16.6.2 The Role of Income 479
16.7 Summary 480
16.8 Further Reading 482
Exercises 482

17 Recreation 485
17.1 Theoretical Model 487
17.1.1 Underlying Assumptions 488
17.1.2 Some Generalizations 489
17.2 Data Structures 491
17.2.1 A Running Example 492
17.3 Empirical Models 493
17.3.1 Demand Systems 494
17.3.2 RUM Models 499
17.3.3 Corner Solution Models 506

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Cambridge University Press
978-1-107-00417-7 — A Course in Environmental Economics
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

17.3.4 Summary of Empirical Models 514
17.4 Modeling Issues 514
17.4.1 Choice Set Definition 515
17.4.2 Opportunity Cost of Time 517
17.4.3 Onsite Time 521
17.4.4 Dynamics 523
17.5 Summary 524
17.6 Further Reading 525
Exercises 525

18 Property Value Models 529
18.1 Hedonic Property Value Models: Theory 530
18.1.1 Consumer's Choice Problem 531
18.1.2 A Running Example 536
18.2 Hedonic Property Value Models: Welfare Measurement 536
18.2.1 Localized Changes in Quality 537
18.2.2 General Equilibrium Effects 539
18.3 Hedonic Property Value Models: Estimation 541
18.3.1 First Stage Estimation 541
18.3.2 Second Stage Estimation 546
18.4 Structural Models 552
18.4.1 Discrete Choice Models 553
18.4.2 Sorting Models 556
18.4.3 Advantages and Disadvantages of a Structural Approach 560
18.5 Quasi-experimental Approaches 561
18.5.1 Background and Motivation 561
18.5.2 Alternative Identification Strategies 564
18.5.3 Structural Versus Quasi-experimental Analysis 567
18.6 Summary 568
18.7 Further Reading 570
Exercises 570

19 Stated Preference Methods 572
19.1 Stated Preference Approaches 574
19.1.1 Contingent Valuation Method 576
19.1.2 Discrete Choice Experiments 579
19.1.3 Contingent Behavior 582
19.2 Empirical Models for Stated Preference Data 583
19.2.1 Binary Choice 583
19.2.2 Discrete Choice Experiments 589
19.3 Incentive Properties of Stated Preference Surveys 592
19.3.1 Incentive Properties of CVM 593
19.3.2 Incentive Properties of Discrete Choice Experiments 595
19.4 Validity 596
19.4.1 Criterion Validity 597
19.4.2 Convergent Validity 599

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CAMBRIDGE

Cambridge University Press
978-1-107-00417-7 — A Course in Environmental Economics
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

19.4.3 Construct Validity 600
19.4.4 Content Validity 601
19.5 Best Practice and Experimental Design 603
19.5.1 Best Practice 604
19.5.2 Experimental Design 607
19.6 Combining SP and RP Data 609
19.6.1 Methodological Topics 609
19.6.2 When Should RP and SP Data Be Combined? 611
19.7 Summary 612
19.8 Further Reading 613
Exercises 614

20 Health Valuation 617
20.1 Mortality Risk Valuation – Modeling 619
20.1.1 Static Model 619
20.1.2 Life Cycle Model 622
20.1.3 Lessons from Theory 627
20.2 Mortality Risk Valuation – Empirical Models 627
20.2.1 Hedonic Wages 628
20.2.2 Stated Preference 632
20.3 Valuing Changes in Morbidity 635
20.3.1 A Model of Health Production 636
20.3.2 Revealed Preference Approaches 637
20.3.3 Stated Preference Approaches 641
20.3.4 Quality-Adjusted Life Years 642
20.4 Summary 642
20.5 Further Reading 644
Exercises 645

PART IV THE PRACTICE OF ENVIRONMENTAL ECONOMICS
21 Cost-Benefit Analysis: Modeling 649
21.1 Discounting 651
21.1.1 Intergenerational Welfare 652
21.1.2 Optimal Growth 654
21.1.3 Uncertainty 655
21.1.4 Empirical Calibration 657
21.2 Integrated Assessment Modeling 660
21.2.1 A Small-Scale Partial Equilibrium Example 661
21.2.2 A Large-Scale General Equilibrium Example 662
21.3 Summary 669
21.4 Further Reading 671
Appendix A: Deriving the Ramsey Equation 671
Appendix B: Proof of Proposition 21.1 672
Appendix C: Deriving (21.30) and (21.31) 673
Exercises 674

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CAMBRIDGE

Cambridge University Press
978-1-107-00417-7 — A Course in Environmental Economics
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

22 Cost-Benefit Analysis: Empirical 676
22.1 Benefits Transfer 677
22.1.1 Terms and Concepts 677
22.1.2 Benefit Function Approaches 679
22.1.3 Defining and Assessing Benefits Transfer Quality 686
22.1.4 Benefits Transfer in Practice 688
22.2 Estimating Abatement Costs 689
22.2.1 Measurement Objectives and Contexts 689
22.2.2 Partial Equilibrium – Retrospective Analysis 692
22.2.3 Partial Equilibrium – Prospective Analysis 700
22.2.4 General Equilibrium 701
22.3 Summary 702
22.4 Further Reading 703
Exercises 703

23 Final Thoughts 705
23.1 An Increasingly Empirical Field 706
23.1.1 Voluntary Pollution Reduction Mechanisms 706
23.1.2 Environmental Justice 707
23.1.3 Productivity and the Environment 708
23.2 Other Omissions 709
23.3 Toolkits 711
23.3.1 Theoretical Models 712
23.3.2 Structural Econometrics 713
23.3.3 Reduced Form Econometrics 714
23.3.4 Experiments 714
23.3.5 Other Skills 715
23.4 Future Research 716
23.5 Closing Thoughts 718

References 719
Author Index 749
Subject Index 752

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CAMBRIDGE

Cambridge University Press
978-1-107-00417-7 — A Course in Environmental Economics
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

Figures

1.1	Efficient pollution level and Pigouvian tax	13
3.1	Pollution damages, costs, and efficient emission level	38
3.2	Emission taxes and auctioned permits	47
3.3	Freely distributed transferable permits	50
3.4	Subsidized abatement	53
4.1	Damage and abatement cost curve uncertainty	63
4.2	Welfare loss with steep and flat marginal damage curves	64
4.3	Illustration of proposition 4.1	66
4.4	Illustration of the Weitzman theorem	69
4.5	Roberts and Spence Instrument	72
4.6	Henry's Instrument	74
4.7	Montero Mechanism with $\beta=0$ or $\beta=1$	80
4.8	Montero Mechanism for firm j	81
5.1	Assumptions on abatement costs	98
5.2	Social optimum	100
5.3	Two optimal environmental taxes	102
5.4	Distribution of rents in auctioned versus freely distributed permits	105
7.1	Interaction between environmental policy and labor/leisure	146
7.2	Tax interaction and revenue effects	147
7.3	Optimal environmental policy with an interaction effect	152
7.4	Optimal environmental policy with a revenue effect	157
7.5	Optimal environmental policy with a pre-existing distortion	161
8.1	Monopsony and monopoly examples	185
8.2	Emissions trading with transaction costs	189
9.1	The unregulated density function of total emissions (solid line) and the density function under an emission tax	226
10.1	Socially optimal level of accident prevention effort	237
10.2	Cutoff levels for compliance with negligence rule	239
10.3	Potential for too much care when insolvency is possible	243
10.4	Behavior under the negligence rule and the second-best due care level	245
11.1	Marginal abatement cost curves with old (0) and new (I) technologies	273

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CAMBRIDGE

Cambridge University Press
978-1-107-00417-7 — A Course in Environmental Economics
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

11.2	Cost savings from technology adoption under two different tax rates	275
11.3	Cost savings from technology adoption under two emission standards	278
11.4	Comparison of adoption incentives under an emission tax and cap and trade	280
11.5	Comparison of adoption incentives under an emission tax and emissions standard	280
11.6	Comparison of adoption incentives under cap and trade and an emissions standard	281
11.7	Optimal position of the aggregate marginal abatement cost function	283
11.8	Social and private value of a process innovation under constant marginal cost	289
11.9	Social and private value of an environmental process innovation under constant marginal cost and constant marginal damage	293
11.10	Possible timing paths for regulator actions	298
11.11	Isoprofit curves, iso-social-cost lines, and the innovator's and regulator's reaction curves	301
13.1a	The phase diagram in the *S/E*-space	362
13.1b	The phase diagram in the S/λ-space	364
13.2a	The optimal time path of the pollution stock, starting with an initial pollution stock exceeding the steady-state value	366
13.2b	The optimal time path of emissions (with an initial pollution stock exceeding the steady-state value)	366
13.2c	The optimal time path of the co-state variable (the Pigouvian tax rate) over time (with an initial pollution stock exceeding the steady-state value)	366
13.2d	The optimal evolution of the pollution stock over time, starting with an initial pollution stock below the steady-state value	366
13.2e	The optimal evolution of emissions over time (with an initial pollution stock below the steady-state value)	367
13.2f	The optimal evolution of the co-state variable (the Pigouvian tax rate) over time (with an initial pollution stock below the steady-state value)	367
13.3a	Optimal time path of the *pollution stock*, starting with an initially *low* pollution stock	373
13.3b	Optimal time path of the *pollution stock*, starting with an initially *high* pollution stock	373
13.3c	Optimal time path of the pollution stock's *shadow price* starting with an initially *low* pollution stock	373
13.3d	Optimal time path of the pollution stock's *shadow price* starting with an initially *high* pollution stock	373
13.3e	The optimal *extraction path* over time, starting with an initially *low* pollution stock	374
13.3f	The optimal *extraction path* over time, starting with an initially *high* pollution stock	374
13.3g	The optimal time path of the remaining *resource stock* (all cases)	374
13.3h	The optimal time path of the *resource shadow price* (all cases)	374
14.1	Price change welfare measures	397
14.2	Quantity change welfare measures	408

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CAMBRIDGE

Cambridge University Press
978-1-107-00417-7 — A Course in Environmental Economics
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

15.1	Weak complementarity	428
15.2	Ordinary vs. compensated demands	430
15.3	Hedonic equilibrium	447
17.1	Corner solution outcome	509
17.2	Labor market outcomes	520
18.1	Household choice outcome	534
18.2	Partial and general equilibrium welfare measurement	538
18.3	Second stage identification problem	548
18.4	Multiple market strategy	550
19.1	Example DCE question from Phaneuf et al. survey	580
19.2	Example DCE question from Mansfield et al. survey	581
20.1	Example choice card from Cameron and DeShazo	634
22.1	Abatement cost concepts	691
22.2	Production possibility set for output and emissions given an input vector	698

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-107-00417-7 — A Course in Environmental Economics
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

Tables

7.1	Numerical results	165
17.1	Selected modeling issues	516
18.1	Examples of first stage hedonic estimation issues	542
18.2	Functional forms for first stage estimation	544
19.1	Abbreviated water quality descriptions from Phaneuf et al. survey	578

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CAMBRIDGE

Cambridge University Press
978-1-107-00417-7 — A Course in Environmental Economics
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

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Cambridge University Press
978-1-107-00417-7 — A Course in Environmental Economics
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

Preface

This book grew out of discussions we had more than ten years ago, when we were both teaching graduate courses in environmental economics at our respective universities in Germany and the United States. Though our interests and skills were different – Requate is a theorist/experimentalist, and Phaneuf an empiricist – we both had the sense that there was something missing in the textbooks we used for our classes. Specifically, while there are a variety of excellent undergraduate and some Master's-level textbooks, there was not a single obvious choice for instructors teaching at the advanced graduate level. For environmental policy design, the classic book by Baumol and Oates (1988), *The Theory of Environmental Policy*, had become dated. For non-market valuation, Freeman (2003) and Freeman et al. (2014), *The Measurement of Environmental and Resource Values*, was (and remains today) an authoritative and obvious choice, but its emphasis is on concepts rather than empirics. As such, there was no single volume suitable for advanced study that presented the theoretical, empirical, and policy aspects of the field as an integrated narrative. As a result, we felt that our students were seeing the trees but not the forest, i.e. they were learning environmental economics as a collection of disjointed topics, but failing to appreciate how the topics fit together into something greater than the sum of their parts. We felt that a textbook for graduate students was needed that: (a) presented the field's canon on environmental policy design and non-market valuation using a single notational convention; (b) included contemporary and advanced topics missing in other sources; (c) reflected the increasingly empirical nature of environmental economics; and (d) conveyed the excitement and dynamism of a growing field. This book is our attempt to meet that need.

Our vision for the book is best explained by discussing its organization. We have divided the material into four parts. In Part I, we set the stage by placing environmental economics in its historical context. This is accomplished by reviewing the field's roots in neoclassical welfare theory and the theory of externalities (Chapter 1), and its close relationship to environmental policy and environmental science (Chapter 2). In Chapter 3 we close Part I by laying out our basic modeling framework for the first half of the book. We define the environmental externality problem and optimal solution, and introduce a variety of environmental policy instruments, which are potentially suitable for decentralizing the social optimum. We also begin to establish criteria that we will

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978-1-107-00417-7 — A Course in Environmental Economics
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

use to evaluate their performance. A main conclusion from Part I is that the portfolio of economic-incentive based policies that we introduce – e.g. emission taxes, cap and trade programs, emission subsidies – are equivalent in their economic efficiency properties.

Our Part I conclusions set up an important benchmark for Part II of the book, in which we add real-world complexity to our description, and investigate the conditions under which the equivalence of the above-mentioned policy tools breaks down. We also study circumstances in which alternative (or complementary) policy instruments are preferred, and when second-best optimal solutions need to be implemented. More specifically, the first several chapters in Part II cover the traditional sub-field of policy design. In Chapters 4 through 9, we consider a range of generalizations and extensions that add nuance to our comparisons of policy instruments. Examples of specific topics include the role of uncertainty in policy design (Chapter 4), considerations related to competitive and non-competitive output markets (Chapters 5 and 6), the role of other, non-environmental distortions in formulating environmental policy (Chapter 7), complications related to spatial considerations and other institutional features (Chapter 8), and the particular problems associated with non-point source pollution (Chapter 9). A common theme in these chapters is that context matters. We show that the equivalence of different economic-incentive based policies holds only in special cases, meaning that effective policy design requires careful consideration of multiple (often competing) factors. These chapters also illustrate how, in its focus on policy-specific challenges, environmental economics has matured beyond an application of the theory of public goods and externalities to the environment.

The last four chapters of Part II cover themes that move beyond the standard suite of policy design topics. For example, in Chapter 10 we provide a detailed treatment of liability rules as an alternative to emission regulations for environmentally risky activities. This is followed in Chapter 11 by a comprehensive discussion of environmental technology development, adoption, and diffusion. In Chapter 12 we discuss several topics that are specific to international environmental problems, including transboundary pollution and international trade. Finally, we close Part II in Chapter 13 by addressing dynamic aspects of externalities – notably models for stock (accumulating) pollutants, and their connection to climate change and non-renewable resource policy.

Throughout Parts I and II of the book, we use conceptual representations of cost and utility functions to characterize policy solutions. Implementation of policy solutions in most instances requires empirical estimates of pollution abatement costs and damage functions, which derive from firms' and households' underlying technology and preference structures. In Part III we turn our attention to the traditional sub-field of non-market valuation, which includes theoretical and empirical tools used to measure the costs and benefits that result from changes in environmental quality. We begin by describing the theoretical basis for applied welfare analysis (Chapter 14), and then discuss the specific assumptions that are needed to calculate non-market values using only observed behavior (Chapter 15). These assumptions give rise to the so-called revealed preference models. In Chapter 16 we present a review of discrete choice econometrics – a class of empirical models that plays a large role in many areas of non-market valuation. These initial Part III chapters provide the conceptual and empirical backgrounds needed for studying the specific techniques and applications that follow. These include recreation demand (Chapter 17), property values (Chapter 18), stated preference methods (Chapter 19), and health valuation (Chapter 20).

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978-1-107-00417-7 — A Course in Environmental Economics
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

We complete the book in Part IV by examining themes related to the practice of environmental economics. Our main task is to discuss, across two chapters, a handful of topics connected to cost-benefit analysis. These include conceptual issues such as discounting and the use of integrated assessment models (Chapter 21), and applied issues related to benefits transfer and estimating abatement cost functions (Chapter 22). We then close the book in Chapter 23 with observations on the increasingly empirical nature of environmental economics, discussions on themes we have not covered, and identification of topics that we believe provide important opportunities for future research.

A distinguishing feature of the book is that we have used a single notational scheme across the four parts of the book in order to connect the various topics and minimize the cost of entry into each new concept. We have also included numerous numbered examples, which we use to describe relevant empirical research, provide intuition with specific functional forms, or place our discussions in the context of a specific policy. A variety of exercises are included at the end of most chapters, which, depending on the chapter's content, are analytical, numerical, empirical, or literature based.[1] In some cases, advanced material or proofs are included in appendices that follow the main content of a chapter. The book's website (www.phaneuf-requate.com) houses data for the empirical exercises as well as supplemental information and errata.

Finally, we have included a "further reading" section at the end of each chapter. It is here that we identify the original source material our discussion has drawn on, and highlight related and in some cases recent research contributions to the area. We have used this approach for two reasons. First, we wrote using a narrative format rather than a review article format, meaning we tried to avoid breaking the flow of description with a large volume of parenthetical references. Thus our citations in the main body of the chapters are usually reserved for attribution of specific ideas, identification of classic sources, and acknowledgment when we have used published material as a model for our textbook presentation. Second, we wanted to have a specific section in each chapter that would serve as a literature-organizing vehicle, where we could classify different areas of inquiry that fit under the chapter's broad themes. We emphasize that our further reading sections are designed to be illustrative rather than comprehensive, and so we have not included citations to many (or even most) of the relevant papers. That said, a book this long that unfolded over many years will undoubtedly have failed to give proper credit in many places, and so the book's website will include expanded versions of our further reading sections, which will be updated periodically.

There are many ways that instructors and students can make use of this book. One possibility is to use the content as the basis for a lecture-based survey of the field. For Master's level survey classes, the early sections in most chapters are accessible and provide the basic canon, while more advanced topics, covered in the later sections, can be skipped. For PhD level survey classes, instructors will have more flexibility to cover the advanced sections and the more technical chapters. A second possibility is to use chapters in the book as background reading for discussion classes focused on contemporary research. For example, students exploring new research at the health-environment nexus may benefit from an initial review of our revealed preference, stated preference, and health valuation chapters. As these different uses suggest, the book does not have

[1] When relevant, the difficulty of individual exercises is indicated using asterisks. One, two, or three asterisks denote basic, intermediate, and advanced problems, respectively.

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Cambridge University Press
978-1-107-00417-7 — A Course in Environmental Economics
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

to be read linearly. A course on environmental policy design could focus on Part I and selected chapters in Part II, while a course on non-market valuation could start directly with Part III and incorporate some material in Part IV. Finally, the book can serve as a reference for the collection of theoretical predictions and empirical methods that environmental economists use in their day-to-day research and teaching.

In terms of technical preparation, readers should have a good understanding of core microeconomic theory. This includes familiarity with consumer demand theory, the theory of the firm, standard duality methods, and general equilibrium concepts. Basic knowledge in game theory, including the concepts of Nash and sub-game perfect equilibria, is useful. In a few instances we use more advanced tools, including mechanism design in Chapter 4 and dynamic optimization in Chapter 13. In these cases we have tried to introduce the needed tools along with the specific concept. Topics that require techniques beyond what is listed above are identified and references provided, but not discussed in detail. Nonetheless, some of the end-of-chapter exercises provide opportunities to explore the advanced areas. For several of the analytical and numerical exercises, familiarity with computational software packages such as Matlab or Mathematica is necessary.

Readers should also have a good understanding of basic econometrics and applied methods. Familiarity with linear regression models and discrete choice econometrics is needed for our applied chapters and to appreciate many of the empirical examples we use throughout. Since discrete choice methods are not always taught in core econometrics classes, we have included a chapter on this subject, which can serve as a point of entry for the interested reader. Experience with applying basic regression and discrete choice models using software tools such as Stata or R is necessary for completing the applied end-of-chapter exercises.

To close the preface, we would like to share a few personal notes and express thanks to the many people and institutions that supported our efforts during the writing of this book. In retrospect, our feeling is that the book was harder to write than expected. Our early plans envisioned translating our respective lecture notes into a narrative, but we quickly discovered that the task of surveying a dynamic and growing field required more than that. As we worked, we became convinced that the book needed to have substantial breadth to represent the range of themes that have occupied environmental economists. At the same time, we did not want to sacrifice depth, since our goal was to provide a genuinely advanced treatment of topics in the field. These two objectives largely explain the book's length and the time it has taken to write. They are also the likely explanations for any limitations that may be present in the final product. Challenging though it was, writing the book was enormously satisfying intellectually, and we are grateful for the opportunity the publisher and our institutions have given us to pursue this work.

A defining characteristic of any multi-year project is that the list of people and organizations to whom thanks is owed is long. We are unable to list here the names of many colleagues and students who read drafts, provided reviews, reacted to ideas, and gave encouragement, but we want to extend our collective thanks for their input. In addition, we have accumulated and presented the ideas in this book, but most of them originated with other people. As such we want to thank the many economists, past and current, who have shaped the field and driven its progress. We also want to acknowledge the authors, reviewers, and publishers of the journals that we have edited during many of our writing

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978-1-107-00417-7 — A Course in Environmental Economics
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

years. Our editing work at *Journal of the Association of Environmental and Resource Economists* (*JAERE* – Phaneuf) and *Journal of Environmental Economics and Management* (*JEEM* – Requate/Phaneuf) has complemented our writing by keeping us abreast of the field's development, expanding our understanding of different topic areas, and introducing us to researchers around the globe.[2]

We would also like to explicitly recognize the institutions that have supported our efforts: North Carolina State University and University of Wisconsin-Madison (Phaneuf), and University of Heidelberg and University of Kiel (Requate). Phaneuf also acknowledges generous support from the NCSU Kriz Faculty Study Leave Endowment, which partially funded his sabbatical visit at the University of Kiel.

[2] At the time of writing, Requate is the Managing Editor for *JEEM* and Phaneuf is the Editor in Chief for *JAERE*. Phaneuf served as *JEEM*'s Managing Editor from 2011 through 2013.

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978-1-107-00417-7 — A Course in Environmental Economics
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

Notational Conventions

The following describes the notation conventions that we generally maintain throughout the book.

STRUCTURAL FUNCTIONS

$D(\cdot)$:	Household pollution damage function
$C(\cdot)$:	Firm abatement cost or general cost function
$\Pi(\cdot)$:	Firm profit function
$U(\cdot)$:	Household or individual direct utility function
$V(\cdot)$:	Household or individual indirect utility function
$P(\cdot)$:	Inverse demand function
$E(\cdot)$:	Household expenditure function (also industry emission level; see below)
$f(\cdot)$,$g(\cdot)$:	Technologies

QUANTITIES

x:	Scalar or vector of consumer demand or firm output levels
p:	Scalar or vector of market prices for x
z:	Scalar consumer good or firm output level; often the numeraire good
l:	Scalar or vector of firm factor input levels
w:	Scalar or vector of firm factor input prices. Also used for household wage rate
y:	Household, individual, or firm income level
e:	Firm level pollution emissions
E:	Industry level pollution emissions (also household expenditure function; see above)
q:	Scalar or vector of an environmental good or quality level
s:	Scalar or vector of agent characteristics
Capital letters:	aggregate outcomes
Lower-case letters:	agent level outcomes

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Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

BEHAVIORAL FUNCTIONS

$x(\cdot)$: Ordinary (uncompensated) demand scalar or vector
$h(\cdot)$: Compensated demand scalar or vector
$\pi^q(\cdot)$: Compensated inverse demand function for quality
$\theta^q(\cdot)$: Uncompensated inverse demand function for quality
$l(\cdot)$: Firm's factor demand function

POLICY PARAMETERS

τ: Pollution tax
ς: Pollution or other subsidy
σ: Price of a pollution allowance in a pollution rights market
α: Relative standard
L: Supply of pollution allowances in a pollution rights market

INDEXES

$i = 1,\ldots,I$: Index of households or individuals
$j = 1,\ldots,J$: Index of firms; also used as index of consumer choice elements in later chapters

OTHER SYMBOLS

$\varepsilon, \eta, \kappa, \nu$: Parameters of structural, behavioral, or econometric functions. Also used for elasticities or response functions
ξ: Unobserved attribute of a quality-differentiated consumer good
β, θ, γ: Symbols commonly used as known or unknown parameters of a model; often the targets of estimation
ρ: State of the world probability. Also used for consumption discount rate
π: General probability

PRONOUNS:

he: Economic agent
she: Analyst or regulator
it: Firm or household

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