CAMBRIDGE

Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

# 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.

**Till Requate** is Professor for Economic Policy at Kiel University, Germany. He was previously Professor for Environmental Economics and Director of the Interdisciplinary Institute of Environmental Economics at Heidelberg University. He is currently Managing Editor of the *Journal of Environmental Economics and Management* and Associate Editor of *Resource and Energy Economics*, and was Chairman of the German Association of Environmental and Resource Economists. He won the European Association of Environmental and Resource Economics' Erik Kempe Award for the best paper in 2004 and the German Society of Health Economics' best paper award in 2013. His research articles have appeared in top field and general economics outlets.

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

CAMBRIDGE

Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

# A COURSE IN ENVIRONMENTAL ECONOMICS

## Theory, Policy, and Practice

**Daniel J. Phaneuf**
*University of Wisconsin-Madison*

**Till Requate**
*University of Kiel, Germany*

CAMBRIDGE UNIVERSITY PRESS

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

CAMBRIDGE

Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

CAMBRIDGE
UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom

One Liberty Plaza, 20th Floor, New York, NY 10006, USA

477 Williamstown Road, Port Melbourne, VIC 3207, Australia

314-321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre, New Delhi - 110025, India

103 Penang Road, #05-06/07, Visioncrest Commercial, Singapore 238467

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9780521178693
10.1017/9780511843839

© Daniel J. Phaneuf and Till Requate 2017

This publication is in copyright. Subject to statutory exception and to the provisions of relevant collective licensing agreements, no reproduction of any part may take place without the written permission of Cambridge University Press.

First published 2017

*A catalogue record for this publication is available from the British Library*

*Library of Congress Cataloging in Publication data*
Names: Phaneuf, Daniel J. (Daniel James), author. | Requate, Till, 1957– author.
Title: A course in environmental economics : theory, policy, and practice / Daniel J. Phaneuf, Till Requate.
Description: New York, NY : Cambridge University Press, 2017. |
Includes bibliographical references and index.
Identifiers: LCCN 2016044938 | ISBN 9781107004177 (hardback) | ISBN 9780521178693 (pbk.)
Subjects: LCSH: Environmental economics.
Classification: LCC HC79.E5 P5125 2017 | DDC 333.7–dc23
LC record available at https://lccn.loc.gov/2016044938

ISBN 978-1-107-00417-7 Hardback
ISBN 978-0-521-17869-3 Paperback

Cambridge University Press has no responsibility for the persistence or accuracy of URLs for external or third-party internet websites referred to in this publication, and does not guarantee that any content on such websites is, or will remain, accurate or appropriate.

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

CAMBRIDGE

Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
Daniel J. Phaneuf , Till Requate
Frontmatter
More Information

*For Tammo, Finja, and Silke – D.P.*

*For Sabine and Frederik – T.R.*

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

CAMBRIDGE

Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
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



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

CAMBRIDGE

Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
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

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

CAMBRIDGE

Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
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 |


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

CAMBRIDGE

Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
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 |


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

CAMBRIDGE

Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
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

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

CAMBRIDGE

Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
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

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

CAMBRIDGE
Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
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

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

CAMBRIDGE
Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
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

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

CAMBRIDGE

Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
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

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

CAMBRIDGE

Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
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

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

CAMBRIDGE

Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
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

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

CAMBRIDGE

Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
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 |




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

CAMBRIDGE

Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
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 $S/\lambda$-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 |


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

CAMBRIDGE
Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
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
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
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 |




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

CAMBRIDGE
Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
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



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

CAMBRIDGE
Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
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).

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

CAMBRIDGE
Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
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.

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

CAMBRIDGE
Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
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

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

CAMBRIDGE

Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
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.

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

CAMBRIDGE

Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
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 |



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

CAMBRIDGE

Cambridge University Press
978-0-521-17869-3 — A Course in Environmental Economics: Theory, Policy, and Practice
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

$\tau$: Pollution tax
$\varsigma$: Pollution or other subsidy
$\sigma$: Price of a pollution allowance in a pollution rights market
$\alpha$: 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
$\xi$: Unobserved attribute of a quality-differentiated consumer good
$\beta, \theta, \gamma$: Symbols commonly used as known or unknown parameters of a model; often the targets of estimation
$\rho$: State of the world probability. Also used for consumption discount rate
$\pi$: General probability

## PRONOUNS:

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

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