

ApEc 8601 Natural Resource Economics

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Lecture hours: Tuesdays & Thursdays, 10:15am – 11:30am, Ruttan Hall B26

Office hours: Monday 1pm – 2pm

Tuesday 1pm – 2pm

By Appointment (Please email or call beforehand)

Course Goals

- Acquaint students with the major themes and seminal literature in natural resource economics.
- Build modeling skills and empirical skills.
- Familiarize students with current natural resources management and policy issues.

Prerequisites

- Master Level Microeconomics (ApEc5151. Applied Microeconomics: Firm and Household or ECON 5151. Elements of Economic Analysis: Firm and Household)
- ApEc8206 Dynamic Optimization: Applications in Economics and Management
- ApEc8202 Mathematical Optimization in Applied Economics (If you have taken ApEc8206 but not ApEc8202, you are fine)

If you do not meet the prerequisites, please come to see me after the first class ASAP.

Textbooks

Reserve materials will be located in Room 240 from 8:30 am-4:30 pm until Waite reopens in mid-September.

We will cover selective chapters in the following books. Since they are put on reserve, you do not necessarily need to own one copy just for the purpose of this class.

- Clark, Colin. 1990. *Mathematical Bioeconomics: The Optimal Management of Renewable Resources*. 2nd Edition, John Wiley & Sons. **(W, M)**
- Nick Hanley, Jason Shogren, Ben White. 2007. *Environmental Economics in Theory and Practice*. 2nd Edition **(W)**
- Kneese and Sweeney (Eds.) 1985. *The Handbook of Natural Resources and Energy Economics*, Vol. I, II and III (available electronically at www.lib.umn.edu)

Note **(W)** means on reserve at Waite Library; **(M)** means on reserve at Magrath Library.

The following books are good alternative sources of reading.

- Conrad, Jon and Colin Clark. 1987. *Natural Resource Economics: Notes and Problems*. Cambridge University Press. **(W, M)**
- Dasgupta, Partha and Geoffrey Heal. 1979. *Economic Theory and Exhaustible Resources*. Cambridge University Press. **(W, M)**

Grading**Total points for the class**

Problem Sets	35
Class Participation	10
Discussion Briefs	15
Midterm Exam	20
Final Exam	20
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Total Points	100

Total points you earned	Your grade	
	A- F System	S-N System
100-93	A	S
93-87	A-	S
87-83	B+	S
83-80	B	S
80-77	B-	S
77-73	C+	S
73-70	C	S
70-67	C-	S
67-63	D+	N
63-60	D	N
60-0	F	N

***Please note that the grade "I" for incomplete is NOT offered in this course.**

*The border-level points belong to the better grade. For example, a total points of 93 is A.

- Problem Sets: Between 7 and 10 Problem Sets.
- Class Participation: Class participation includes asking questions, answering questions and contributing to discussions. Out of the 10 points, 4 points are allocated to participation in general classes and 6 points are allocated to the three discussion classes (2 points each).
- Discussion Briefs (see examples): Three discussion briefs (5 points each). The discussion briefs should be two pages and singled-spaced. If you have a long proof, put it in an appendix. The purpose of discussion briefs is to encourage you to think critically about resource issues, identify researchable questions, and choose modeling strategies. You can focus on a topic we cover in class (e.g., fishery management) or assemble a set of papers from the Reading List. In the discussion brief, first summarize the main points discussed in class or in the papers you have selected (e.g., main policy issues, critical assumptions of theoretical models, modeling framework, the most important things you have learned), then provide **your own view** (e.g., why a policy has failed or succeeded, how a model can be extended/modified, application of a paper/model to new resource problems, the most important unanswered question/future direction of research). Grades of discussion briefs will mostly be determined by the **critical thinking** part. If you are not sure what to write about, you can always discuss with me first.
- Exams will be in class and closed books. Collaboration is NOT allowed in exams. The midterm exam covers renewable resources. The final exam is NOT comprehensive. It is more like a second midterm and only covers materials after the midterm. **Students must take the midterm and final exams at the designated time unless under extreme conditions such as medical reasons (doctor's proof required) and with my permission. If you skip any exam without obtaining my permission beforehand, your default grade for the exam is zero. NO retake is allowed.**

Classroom Rules

Be on time for classes. No cellphone/iphone/ipad. Questions and discussions relevant to lectures are more than welcome.

Guideline for the Term Paper

Instead of writing 3 discussion briefs, you have the option to write one short term paper. Your score on the term paper, if higher than the score of your final exam, can also be used to replace the score of the final exam.

Topic

You may choose to work on any topic as long as it is in the field of natural resource economics. A good way to find a topic is to start by reading several papers in an area that is of interest to you.

You may choose to do a theoretical paper or an empirical paper. A theoretical paper can be the development of a new theory, or the extension of existing theory, or building on an existing model by changing an assumption (about behavior, policy environment etc.). Often propositions/hypotheses are developed either using comparative dynamics or simulations (if analytical solutions are difficult to find).

An empirical paper applies an existing theory or methodological approach to a new problem; or tests a theory and/or behavior assumption; or studies the same problem using a different data set. You should make sure you have the data you need beforehand.

I. Abstract

The abstract will be more like the abstract you write for the AAEA annual meeting. It should briefly describe the background and motivate your research topic, describe theoretical model/approach/data you will use in the paper, and expected results. The word limit is 1,000 words. Think of this as an outline for your paper.

II. Manuscript

The paper should be less than 20 pages (double space, font size 12, margin 1 inch, appendices and references not included). Appendices should not be longer than 5 pages. The paper should have the following elements.

▪ **Introduction**

- The issue to be studied / the research question to be answered.
- Motivation: why is this question important? For an empirical paper, what is the policy relevancy?
- Literature review: Please do not list all the papers you have read. A good literature review can be done in one or two paragraphs: discuss the contribution (and drawbacks) of the key papers that address the topic in a few sentences; point out the gap in the literature, i.e., what is not done in previous studies.
- Contribution to the literature: If you want to make this term paper part of your dissertation or something that can be published in the future, you need to think hard on this part. For the purpose of this course alone, the paper only requires some degree of originality.

▪ **Theoretical Model**

- Assumptions used in the model
- Define the optimization problem (the objective functional¹ and constraints)
- Derive the optimality conditions (only key steps, details can be put in appendices)

¹ Notice the objective functional is a terminology in dynamic optimization.

➤ Derive comparative dynamics

- **Data description (if an empirical paper)**
- **Empirical Model and Estimation Methods (if an empirical paper)**

- **Results and Discussion**

Discuss the findings, provide some intuition

- **Conclusion**

Draw policy implications. You can combine conclusion section with results and discussion section.

- **References**

Cited literature.

- **Tables and Figures**

One table/figure on each page. Table and figure should stand alone (fully descriptive).

Style and Writing

While the ideas and the quality of the analysis are the most important things in the paper, the style matters as well. Paper should be done in a style that is appropriate for a publication in an economics journal. This can be learned by paying attention to writing styles when you read articles in *Journal of Environmental Economics and Management*. Of greatest importance is that your paper be well organized and clearly written.

Writing is hard work. You have to keep write and rewrite and rewrite. I suggest you write an outline of each section (that is, the topic sentence of each paragraph), read the outline to see if the story flows, revise the outline, start to fill in each paragraph (remember, the principle is one paragraph, one idea, do not put too many things in one paragraph. If your paragraph is one page long, it is probably too long). After you are done with one section, put it aside for a while, then read it again to see if it makes sense to you, then revise. Writing is a logical process. Do not just throw in anything that comes to your mind. Organize your arguments and proceed in a logical order.

Timeline for Term Paper and Related

September	Schedule an appointment with me to talk about your idea on the paper. You need to narrow down to a specific topic by then and have a general outline of the paper.
October 2nd	Abstract due.
November 30th	Draft due. I will try to provide comments within a week.
December 20th	Responses to my comments due. You may not have enough time to revise the paper significantly. So you will write about how to address major comments I have raised.

Grading: Out of 15 points, 3 points for research idea (innovative, contribution to the literature), 7 points for modeling or estimation, 1 point for literature review, 1 point for policy implications/conclusions, 3 points for general writing and organization of the paper.

Tentative Lecture Schedule

Dates		Topic
Tu	Sep 4	Introduction Review of dynamic optimization
Th	Sep 6	Fishery – Optimal Harvesting // Review of dynamic optimization
Tu	Sep 11	Fishery – Optimal Harvesting// Review of dynamic optimization
Th	Sep 13	Biological growth process
Tu	Sep 18	Fishery – Open Access
Th	Sep 20	Fishery – Regulated Open Access and Management Issues
Tu	Sep 25	Common Property Resources: Game Theoretic Models
Th	Sep 27	Common Property Resources: Game Theoretic Models
Tu	Oct 2	Forestry
Th	Oct 4	Forestry
Tu	Oct 9	Forestry
Th	Oct 11	Water Resources
Tu	Oct 16	Discussion 1
Th	Oct 18	From theory to empirical: Estimation
Tu	Oct 23	Midterm Exam
Th	Oct 25	Spatially Explicit Models
Tu	Oct 30	Spatially Explicit Models
Th	Nov 1	Invasive Species, Guest Lecture by Professor Frances Homans
Tu	Nov 6	Basic Hotelling Model and Extensions
Th	Nov 8	Empirical Tests of Hotelling Model and Imperfect Competition
Tu	Nov 13	Discussion 2
Th	Nov 15	Energy policy issues
Tu	Nov 20	Renewable Resource Management with Uncertainty
Tu	Nov 27	Renewable Resource Management with Uncertainty
Th	Nov 29	Irreversibility, Uncertainty, and Option Value
Tu	Dec 4	Irreversibility, Uncertainty, and Option Value
Th	Dec 6	Empirical Dynamic Programming
Tu	Dec 11	Discussion 3
W	Dec 19	Final Exam 10:30am-12:30pm

* indicates required readings (papers that are covered in class).

Renewable Resources Reading List

Fishery Economics Textbook Reading

*Clark, Chapter 2

*Hanley, Shogren and White, Chapter 10 in 1st Edition or Chapter 9 in 2nd Edition

I. Fishery – Optimal Harvesting

*Clark, C. and G. Munro. 1975. The Economics of Fishing and Modern Capital Theory: A Simplified Approach. *Journal of Environmental Economics and Management* 2: 92-106.

*Spence, M. and D. Starrett. 1975. Most Rapid Approach Paths in Accumulation Problems. *International Economic Review* 16: 388-403.

*Clark, Sections 4.2; Section 3.3.

Conrad, J. 1989. Bioeconomics and the Bowhead Whale. *Journal of Political Economy* 97: 974-987.

Clark, C. 1973. Profit Maximization and the Extinction of Animal Species. *Journal of Political Economy* 81: 950-961.

II. Biological Growth Processes

*Clark, Chapter 1

*Clark, Sections 7.1 – 7.5 (Delays & Periodic/seasonal effects)

Wilén, J. 1985. Bioeconomics of Renewable Resource Use, in Kneese and Sweeney (Eds.), *Handbook of Natural Resource and Energy Economics* Vol. 1. Instead of reading Clark Chapter 1 and 7.1 – 7.5, you can read Wilén's chapter. It has good coverage in Capital Theory as well as Bioeconomics.

Clark, Chap 9.2, 9.5 – 9.7 (Age structure and related effects)

III. Open Access

*Gordon, H.S. 1954. The Economic Theory of a Common Property Resource: The Fishery. *Journal of Political Economy* 62: 124-142.

*Scott, A. 1955. The Fishery: The Objective of Sole Ownership. *Journal of Political Economy* 63: 116-124.

*Smith, V. 1968. Economics of Production from Natural Resources. *American Economic Review* 58: 409-431.

➤ Fullenbaum, R., E. Carlson, and F. Bell. 1971. Economics of Production from Natural Resources: Comment. *American Economic Review*, 61: 483-487.

➤ Smith, V. 1971. Economics of Production from Natural Resources: Reply. *American Economic Review* 61: 488-491.

Bjørndal, T. and J. Conrad. 1987. The Dynamics of an Open Access Fishery. *Canadian Journal of Economics* 20: 74-85.

Stavins, R. 2011. The Problem of the Commons: Still Unsettled after 100 Years. *American Economic Review* 101(1): 81–108.

IV. Regulated Open Access and Management Issues

- *Homans, F. and J. Wilen. 1997. A Model of Regulated Open Access Resource Use. *Journal of Environmental Economics and Management* 32: 1-21.
 - *Homans, F. and J. Wilen. 2005. Markets and rent dissipation in regulated open access fisheries, *Journal of Environmental Economics and Management* 49: 381-404.
- *Wilen, J. 2000. Renewable Resource Economists and Policy: What Differences Have We Made? *Journal of Environmental Economics and Management* 39: 306-327.
- Beddington, J., D. Agnew, and C. Clark. 2007. Current problems in the management of marine fisheries. *Science* 316, 1713-1716.
- Worm, B., et al., 2009. Rebuilding Global Fisheries. *Science* 325: 578-585
- Costello, C., S. Gaines, and J. Lynham. 2008. Can Catch Shares Prevent Fisheries Collapse? *Science* 321: 1678 – 1681
- Clark, Introduction. Has good overview of resource problems in economics terms.
- Clark, Chapter 8

V. Common Property Resources: Game Theoretic Models

- *Levhari, D., and L. Mirman. 1980. The Great Fish War: An Example Using a Dynamic Cournot-Nash Solution. *Bell Journal of Economics* 11: 322-334.
- *Negri, D. 1989. The common property aquifer as a differential game. *Water Resources Research* 25: 9-15.
- *Polasky, S., N. Tarui, G. Ellis and C. Mason. 2006. Cooperation in the Commons. *Economic Theory* 29: 71–88.
- Dockner and Long. 2001. Differential Games in Resources and Environmental Economics, in *Differential Games in Economics and Management Science*.
- Ostrom, E. 1990. Governing the Commons: The Evolution of Institutions for Collective Action.
- McWhinnie, S. 2009. The tragedy of the commons in international fisheries: An empirical examination. *Journal of Environmental Economics and Management* 57: 321-333.
- Agrawal, A. 2001. Common Property Institutions and Sustainable Governance of Resources. *World Development* 29: 1649-1672.

VI. Forestry

- *Clark, Chapter 9
- *Hanley, Shogren and White, Chapter 11 in 1st Edition or Chapter 10 in 2nd Edition
- *Bowse, M. and J. Krutilla. 1985. Chapter 12 Multiple Use Management of Public Forestlands in Kneese and Sweeney (Eds.) *Handbook of Natural Resource and Energy Economics 2*: 531-569.
- *Reed, W. 1986. Optimal Harvesting Models in Forestry Management -A Survey. *Natural Resource Modeling 1*: 55-79.
- *Pfaff, A. 1999. What drives deforestation in the Brazilian Amazon? Evidence from satellite and socioeconomic data. *Journal of Environmental Economics and Management 37*: 26-43.
- Blackman, A. Will REDD Really Be Cheap? February 5, 2010. RFF Weekly Policy Commentary.
- Hartman, R. 1976. The Harvesting Decision when a Standing Forest has Value. *Economic Inquiry 14*: 52-58.
- Heaps, T. 1984. The Forestry Maximum Principle. *Journal of Economic Dynamics & Control 7*: 131-151.

VII. Water Resources

- *Burt, O. 1964. Optimal resource use over time with an application to ground water. *Management Science 11*: 80-93.
- *Provencher, B., and O. Burt. 1993. The externalities associated with the common property exploitation of groundwater. *Journal of Environmental Economics and Management 24*: 139-158.
- *Gisser, M., and D. Sanchez. 1980. Competition versus optimal control in groundwater pumping. *Water Resources Research 16*: 638-642.
 - Allen, R., and M. Gisser. 1984. Competition versus optimal control in groundwater pumping when demand is nonlinear. *Water Resources Research 20*: 752-756.
 - Brill, T., and H. Burness. 1994. Planning versus competitive rates of groundwater pumping. *Water Resources Research 30*: 1873-1880.
 - Rubio, S. and B. Casino. 2001. Competitive versus efficient extraction of a common property resource: The groundwater case. *Journal of Economic Dynamics & Control 25*: 1117-1137
- Tsur, Y., and T. Graham-Tomasi. 1991. The buffer value of groundwater with stochastic surface water supplies. *Journal of Environmental Economics and Management 21*: 201-224.
- Knapp, K., and L. Olson. 1995. The Economics of Conjunctive Groundwater Management with Stochastic Surface Supplies. *Journal of Environmental Economics and Management 28*: 340-356.

VIII. Empirical papers

- *Ramón López. 1998. The Tragedy of the Commons in Côte d'Ivoire Agriculture: Empirical Evidence and Implications for Evaluating Trade Policies, *World Bank Economic Review* 12 (1): 105-131
- *Bohn, H., and R. Deacon. 2000. Ownership risk, investment, and the use of natural resources. *American Economic Review* 90(3): 526-549
- Zhang, J. and M. Smith. 2011. Estimation of a Generalized Fishery Model: A Two-Stage Approach. *The Review of Economics and Statistics* 93(2): 690–699.

IX. Spatially Explicit Models

- *Sanchirico, J. and J. Wilen. 2005. Optimal Spatial Management of Renewable Resources: Matching Policy Scope to Ecosystem Scale. *Journal of Environmental Economics and Management* 50: 23-46.
 - Sanchirico, J. and J. Wilen. 1999. Bioeconomics of Spatial Exploitation in a Patchy Environment. *Journal of Environmental Economics and Management* 37: 129-150.
- *Smith, M. and J. Wilen. 2003. Economic impacts of marine reserves: the importance of spatial behavior. *Journal of Environmental Economics and Management* 46: 183-206.
 - Smith, M. 2010. Political economy of marine reserves: Understanding the role of opportunity costs. *Proceedings of the National Academy of Sciences of the United States of America* 107: 18300 -18305
 - Smith, M., J. Zhan, F. Coleman, 2008, Econometric modeling of fisheries with complex life histories: Avoiding biological management failures. *Journal of Environmental Economics and Management* 55: 265-280.
- Smith, M., J. Sanchirico and J. Wilen. 2009. The economics of spatial-dynamic processes: Applications to renewable resources. *Journal of Environmental Economics and Management* 57: 104-121
- Brock, W. and A. Xepapadeas. 2008. Diffusion-induced instability and pattern formation in infinite horizon recursive optimal control. *Journal of Economic Dynamics & Control* 32: 2745-2787.
- Polasky et al., 2008. Where to put things? Spatial land management to sustain biodiversity and economic returns. *Biological Conservation* 141: 1505 - 1524.

Non-Renewable Resources Reading List

Text book Reading

Hanley, Shogren and White, Chapter 9 in 1st Edition, or Chapters 7 and 8 in 2nd Edition

I. The Basic Hotelling Model and Extensions

(1). Basic Hotelling Model

*Hotelling, H. 1931. The Economics of Exhaustible Resources. *Journal of Political Economy* 39: 137-175.

Solow, R. 1974. The Economics of Resources or the Resources of Economics. *American Economic Review* 64:1-14.

Levhari, D. and N. Liviatan. 1977. Notes on Hotelling's Economics of Exhaustible Resources. *Canadian Journal of Economics* 10:177-192.

Devarajan, S. and A. Fisher. 1981. Hotelling Economics of Exhaustible Resources - 50 Years Later. *Journal of Economic Literature* 19: 65-73.

(2). Scarcity Rent

*Krautkraemer, J. 1998. Nonrenewable Resource Scarcity. *Journal of Economic Literature* 36: 2065-2107.

Krautkraemer, J. 2005. The Economics of Natural Resource Scarcity: The State of the Debate. In Simpson, D., M. Toman, and R. Ayres (Eds) *Scarcity and Growth Revisited: Natural Resources and the Environment in the New Millennium*. Resources for the Future, Washington, DC.

Gray, L. 1914. Rent under the Assumptions of Exhaustibility. *Quarterly Journal of Economics* 28: 466-489.

Farzin, H. 1992. The Time Path of Scarcity Rent in the Theory of Exhaustible Resources. *The Economic Journal*, 102: 813-830.

(3). Extraction Cost

Solow, R. and F. Wan. 1976. Extraction Costs in the Theory of Exhaustible Resources. *Bell Journal of Economics*, 7:359-370.

(4). Exploration

Pindyck, R. 1978. The Optimal Exploration and Production of Nonrenewable Resources. *Journal of Political Economy* 86: 841-861.

Hartwick, J. 1978. Exploitation of Many Deposits of an Exhaustible Resource. *Econometrica* 46: 201-217.

II. Empirical Tests of Hotelling Model

*Slade, M. 1982. Trends in Natural-Resource Commodity Prices: An Analysis of the Time Domain. *Journal of Environmental Economics and Management* 9: 122-137.

*Halvorsen, R. and T. Smith. 1991. A Test of the Theory of Exhaustible Resources. *Quarterly Journal of Economics*, 123-140.

Farrow, S. 1985. Testing the Efficiency of Extraction from a Stock Resource. *Journal of Political Economy* 93: 452-487.

Miller, M. and C. Upton. 1985. A Test of the Hotelling Valuation Principle. *Journal of Political Economy* 93: 1-15.

- Chermak, J. and R. Patrick. 2001. A microeconomic test of the theory of exhaustible resources. *Journal of Environmental Economics and Management* 42: 82-103.
- Livernois, J. 2009. On the empirical significance of the Hotelling Rule. *Review of Environmental Economics and Policy* 3: 22-41.

III. Imperfect Competition

- *Stiglitz, J. 1976. Monopoly and the Rate of Extraction of Exhaustible Resources. *American Economic Review* 66: 655-661.
- *Salant, S. 1976. Exhaustible Resources and Industrial Structure: Nash-Cournot Approach to World Oil Market. *Journal of Political Economy* 84: 1079-1093.
- Pindyck, R. 1978. Gains to Producers from the Cartelization of Exhaustible Resources. *Review of Economics and Statistics* 60: 238-251.
- Salo, Seppo, and Olli Tahvonen, 2001, Oligopoly equilibria in nonrenewable resource markets, *Journal of Economic Dynamics and Control* 25, 671–702

IV. Energy Policy Issues

- *Gillingham, K., R. Newell and K. Palmer. 2009. Energy Efficiency Economics and Policy. *Annual Review of Resource Economics* 1: 597–620.
- *Sharp, P. 2009. Reflections on Three Decades of Energy Policy. *Resources* Winter: 3-4.
- Hayes, K. 2011. Toward a New National Energy Policy. *Resources* Winter/Spring: 19-22. There is a RFF report of the same title that you can read in details.
- *Fargione, J., J. Hill, D. Tilman, S. Polasky and P. Hawthorne. 2008. Land Clearing and the Biofuel Carbon Debt. *Science* 319: 1235-1238.
- *Greening, L., D. Greene and C. Dfiglio. 2000. Energy efficiency and consumption - the rebound effect - a survey. *Energy Policy* 28: 389-401.
- Klier, T. and J. Linn. The Price of Gas and the Demand for Fuel Economy: Are There Any Links? October 23, 2009, RFF Weekly Policy Commentary.
- *Allcott, H. and S. Mullainathan. 2009. Behavior and Energy Policy. *Science* 327: 1204–1205.
- Anderson, S. and J. Sallee. 2011. Using Loopholes to Reveal the Marginal Cost of Regulation: The Case of Fuel-Economy Standards, *American Economic Review* 101: 1375–1409.

Uncertainty and Irreversibility

*Hanley, Shogren and White, 8.5; 9.9; 10.8; 12.2.3. (W)^{on reserve at Waite Library}

Dixit, A. and R. Pindyck. 1994. *Investment under Uncertainty*. Chap 1 (1, 2, 3), Chapter 2, 3 and Chapter 4 (1, Appendix A). (W)^{on reserve at Waite Library}

I. Renewable Resource Management with Uncertainty

*Cropper, M. 1976. Regulating Activities with Catastrophic Environmental Effects. *Journal of Environmental Economics and Management* 3: 1-15.

*Reed, W. 1979. Optimal Escapement Levels in Stochastic and Deterministic Harvesting Models. *Journal of Environmental Economics and Management* 6: 350-363.

➤ Sethi, G., C. Costello, A. Fisher, M. Hanemann and L. Karp. 2005. Fishery management under multiple uncertainty. *Journal of Environmental Economics and Management* 50: 300-18.

*Pindyck, R. 1984. Uncertainty in the theory of renewable resource markets. *Review of Economic Studies* 51: 289-303.

*Reed, W. 1984. The effects of the risk of fire on the optimal rotation of a forest. *Journal of Environmental Economics and Management* 11: 180-190.

➤ Yin R. and D. Newman. 1996. The effect of catastrophic risk on forest investment decisions. *Journal of Environmental Economics and Management* 31: 186-197.

Costello, C. and S. Polasky. 2008. Optimal Harvesting of Stochastic Spatial Resources. *Journal of Environmental Economics and Management* 56: 1-18.

Newell, R. and W. Pizer. 2003. Regulating stock externalities under uncertainty. *Journal of Environmental Economics and Management* 45 (2, Supplement 1): 416-432.

Weitzman, M. 2002. Landing fees vs harvest quotas with uncertain fish stocks. *Journal of Environmental Economics and Management* 43: 325-338.

II. Non-Renewable Resource Management with Uncertainty

Pindyck, R. 1980. Uncertainty and Exhaustible Resource Markets. *Journal of Political Economy* 88: 1203-1225

Loury, G. 1978. The Optimal Exploitation of an Unknown Reserve. *Review of Economic Studies* 45: 621-636.

III. Irreversibility, Uncertainty, and Option Value

*Perrings, C. and W. Brock. 2009. Irreversibility in Economics. *Annual Review of Resource Economics* 1: 219-238.

*Mezey, E. and J. Conrad. 2010. Real Options in Resource Economics. *Annual Review of Resource Economics* 2: 33-52.

Arrow, K. and A. Fisher. 1974. Environmental Preservation, Uncertainty, and Irreversibility, *Quarterly Journal of Economics* 88: 312-319. [ApEc8602 required reading]

Henry C. 1974. Investment decisions under uncertainty: the "Irreversibility Effect." *American Economic Review* 64: 1006-12.

➤ Hanemann, M. 1989. Information and the Concept of Option Value, *Journal of Environmental Economics and Management* 16: 23-37.

- Fisher, A. and M. Hanemann. 1987. Quasi-Option Value — Some Misconceptions Dispelled. *Journal of Environmental Economics and Management* 14: 183-190.
- Pindyck, R. 1991. Irreversibility, Uncertainty, and Investment. *Journal of Economic Literature* 29: 1110-1148.
- Dixit, A. 1992. Investment and Hysteresis. *Journal of Economic Perspectives* 6: 107-132.
- Krutilla, J. 1967. Conservation Reconsidered, *American Economic Review* 57: 777- 786.
- Fisher, A. 2000. Investment under Uncertainty and Option Value in Environmental Economics. *Resource and Energy Economics* 22: 197-204.
- Insley, M. 2002. A real options approach to the valuation of a forestry investment. *Journal of Environmental Economics and Management*. 44(3): 471-492.