University of Minnesota
Department of Applied Economics

Natural Resource Economics
APEC 8601
Fall Semester 2016
Tu/Th 10:15 – 11:30, McNeal 10

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Course Content and Objectives

This course has two main objectives:

- To acquaint you with the major issues and seminal literature in natural resource economics. We will cover issues related to the use of renewable resources such as fisheries, aquifers, and timber, and non-renewable resources such as oil and minerals. We will also cover issues related to the conservation of biodiversity and provision of ecosystem services, climate change, and sustainability. We will analyze the issue of efficient use of resources over time and under what conditions market equilibrium achieves an efficient outcome, intergenerational equity and discounting, common property resources, imperfect competition, spatial modeling, uncertainty, and irreversible decisions.

- To increase your ability to do economic research. We will do a set of activities to increase your ability to think critically and formulate specific researchable questions, as well as improving your modeling and analytical skills.

Prerequisites

APEC 8000-8004 or equivalent (graduate level microeconomic theory). It is possible to take microeconomic theory concurrently. If you haven't had such classes (or are taking them concurrently) please talk to me about what you will need to do to keep up. It is also desirable to have taken APEC 8206 – Dynamic Optimization. We will adjust the course based on how familiar students are with the techniques of dynamic optimization (optimal control theory and dynamic programming). If you do not have an adequate background in dynamic optimization or microeconomic theory but feel you can handle the material please talk with me and we will arrange a way for you to catch up on what you need to know.

Course Requirements

Class participation	5%
Weekly insights	10%
Problem sets	25%
Research paper first draft	5%
Peer reviews	5%
Research paper final draft	20%
Midterm 1	15%
Midterm 2	15%

We will read and discuss major articles that have helped define the field of natural resource economics and recent articles on the frontier. Readings for the course will be made available on the Moodle website for the course: https://ay16.moodle.umn.edu/course/view.php?id=2897.
Reading the literature is important for gaining literacy and understanding the evolution of ideas and analytical techniques. Class time will be largely devoted to lecture and discussion of this material. For good discussion it is important to come to class prepared. Please do the readings assigned ahead of the class period when they will be discussed. Doing so will make the class more rewarding and more enjoyable. I will try to be clear on what I expect you to read and when.

Each week you will write up a question or insight arising from lecture, class discussion, class readings, other readings, or recent events. These will be due at 6 pm on Wednesday and can be submitted electronically on the course Moodle website. These insights/questions are meant to be short (several sentences is sufficient) and focused on a particular question or issue that you would like to know more about. At the start of class on Thursday we will spend some time discussing selected issues raised by your submissions. We will use this time to think critically about the issue, formulate specific researchable questions, and potential modeling strategies. Often these sessions turn into a quick "how to model" or "how to design research" on the question. I would be happy if one or more of these blossomed into research papers for the course or full-fledged research projects.

There will be periodic problem sets. The best way to learn natural resource economics (or any branch of economics) is to solve problems. The problem sets will be mostly analytical but will also include some numerical problems. Some problem sets will require proficiency in the use of *Matlab* and we will spend time to learn *Matlab* skills as needed. I encourage you to work together on problem sets but each of you must hand in your own assignment.

The best way to learn to do research is to do it. Each student will write a research paper in the course. The research paper will be short, on the order of 5 – 8 pages double-spaced, and focused on a specific research question (you only have 5- 8 pages so you really do need to be focused). For the paper please pick a well-defined problem and develop an analytical or simulation model, or conduct an empirical analysis, to address the problem. A good way of thinking about this assignment is to have a topic along the lines of a problem for a problem set, but one that hasn't been formulated previously, or an extension of an existing paper in the literature. To help you get to a good final product, you will first hand in an outline. After receiving comments on the outline, you will then write a first draft. The first draft will be read by two classmates who will serve as peer reviewers (as is done at a professional journal). The peer reviewers will provide you with written comments on the strength and weaknesses of the draft and suggestions for improvement. I will also read and comment on the first draft. You will then "revise and resubmit" the paper taking account of the three sets of comments. More details on the paper assignment and peer reviewing will handed out later in the course.

There will be two tests on the material, one around midterm and the other near the end of the semester.

The two tests will be equally weighted except in the case where a student does much better on the second test in which case the second test will get greater weight.

Texts

There are three books that we will reference fairly extensively in the course (only one of which I have asked you to purchase – Conrad and Clark):

Clark, C. 1990. *Mathematical Bioeconomics: The Optimal Management of Renewable Resources* (2nd Ed.). John Wiley.

Conrad, J. and C. Clark. 1987. *Natural Resource Economics: Notes and Problems*. Cambridge University Press.

Dasgupta, P. and G. Heal. 1979. *Economic Theory and Exhaustible Resources*. Cambridge University Press.

Clark (1990) contains useful discussion of renewable resource models (but is really expensive so I'm not asking you to buy it). Conrad and Clark (1987) contain a summary of important concepts and a set of exercises that will allow you to apply the concepts to resource problems. I will assign some exercises from this book on problems set. Dasgupta and Heal (1979) contains useful discussion of non-renewable resource models. Most of the readings for the course are journal articles. These articles will be available on the course Moodle website.

There are several other useful books that are good reference books that you may wish to purchase or have access to:

1. Natural Resource Economics

    a. Clark, C. W. 1985. *Bioeconomic Modelling and Fisheries Management*. John Wiley and Sons.
    b. Conrad, J. 2010. *Resource Economics* 2nd edition. Cambridge University Press
    c. Grafton, Adamowicz, Dupont, Nelson, Hill, Renzetti. 2004. *The Economics of the Environment and Natural Resources*. Wiley.
    d. Halvorsen and Layton. 2015. *Handbook on the Economics of Natural Resources*. Edward Elgar.
    e. Hanley, Shogren and White. 2007. *Environmental Economics in Theory and Practice* 2nd edition. Palgrave MacMillan.
    f. Hartwick and Olewiler. 1998. *The Economics of Natural Resource Use* (2nd Ed)
    g. Maler and Vincent. 2005. *The Handbook of Environmental Economics*, Vol. I,II and III. Elsevier.

2. Dynamic Optimization

    a. Caputo, M. 2005. *Foundations of Dynamic Economic Analysis: Optimal Control Theory and Applications*. Cambridge University Press.
    b. Chiang, A. 2000. *Elements of Dynamic Optimization*. McGraw Hill.
    c. Dixit, A. and R. Pindyck. 1994. *Investment under Uncertainty*. Princeton University Press.
    d. Dockner, E., S. Jorgensen, N.V. Long, and G. Sorger. 2001. *Differential Games in*

Economics and Management Science. Cambridge University Press.

e. Kamien, M.I. and N.L. Schwartz. 2012. *Dynamic Optimization* 2nd edition. Dover Publications.
f. Leonard, D. and N.V. Long. 1992. *Optimal Control Theory and Static Optimization in Economics*. Cambridge University Press.
g. Seierstad, A. and K. Sydsaeter. 1987. *Optimal Control Theory with Economic Applications*. Elsevier.
h. Stokey, N.L. and R.E. Lucas Jr. 1989. *Recursive Methods in Economic Dynamics*. Harvard University Press.

Policies

Late Assignments

All assignments are due at the beginning of class on the due date. If you have extenuating circumstances that will prevent you from turning in an assignment on time please arrange for an extension ahead of time. Putting off assignments until the very end and then having a last minute crisis is your problem not mine. Students who turn in assignments after the due date without a valid excuse will have their grades reduced by one grade (e.g. A- to B+) for each day the assignment is late.

Academic Dishonesty and Plagiarism

The University of Minnesota defines academic dishonesty as "Submission of false records of academic achievement; cheating on assignments or examinations; plagiarizing; altering, forging, or misusing a University academic record; taking, acquiring, or using test materials without faculty permission; acting alone or in cooperation with another to falsify records or to obtain dishonestly grades, honors, awards, or professional endorsement" (University of Minnesota's Board of Regents Student Conduct Code). Plagiarism is the "use the words or ideas of another person as if they were your own words or ideas" (Merriam Webster Dictionary). If you want to use the exact wording from a previously published work in your own work you must put the wording in quotation marks and cite the source (as shown by example in the prior sentence). If you use ideas or specific facts from a source but do not use the exact words then you still must cite the source of the original ideas or facts. Evidence of academic dishonesty will be forwarded to the Student Scholastic Conduct Committee. TurnItIn is used to check for plagiarism on written assignments.

Credits and Workload Expectations

One credit is defined as equivalent to an average of three hours of learning effort per week (over a full semester) necessary for an average student to achieve an average grade in the course. For example, a student taking a three credit course that meets for three hours a week should expect to spend an additional six hours a week on coursework outside the classroom.

Students with Disabilities

The University of Minnesota is committed to providing equitable access to learning opportunities for all students. Disability Services (DS) is the campus office that collaborates with students who have disabilities to provide and/or arrange reasonable accommodations. If you have, or think you may have, a disability (e.g., mental health, attentional, learning, chronic health, sensory, or physical), please contact DS at 612-626-1333 to arrange a confidential discussion regarding equitable access and reasonable accommodations. If you are registered with DS and have a current letter requesting reasonable accommodations, please let me know early in the semester so we can agree on accommodations that will be applied in the course.

Students with Mental Health Issues

As a student you may experience a range of issues that can cause barriers to learning, such as strained relationships, increased anxiety, alcohol/drug problems, feeling down, difficulty concentrating, and/or lack of motivation. These mental health concerns or stressful events may lead to diminished academic performance or reduce your ability to participate in daily activities. University of Minnesota services are available to assist you with addressing these and other concerns you may be experiencing. You can learn more about the broad range of confidential mental health services available on campus via www.mentalhealth.umn.edu.

Reading List

I. The Big Picture: Resources and Sustainable Development

Arrow, K., et al. 1995. Economic growth, carrying capacity, and the environment. *Science* 268: 520-521.

Tierney, J. 1990. Betting the planet. *The New York Times Magazine*, Dec. 2, 1990.

Millennium Ecosystem Assessment. 2005. Summary for decision-makers. Pages 1 – 24 in *Living Beyond Our Means: Natural Asset and Human Well-Being*. Island Press.

Rockström, J., et al. 2009. A safe operating space for humanity. *Nature* 461: 472-475.

Johnson, D.G. 2000. Population, food and knowledge. *American Economic Review* 90: 1-14.

Barbier, E.B. 2007. *Natural Resources and Economic Development*. New York: Cambridge University Press.

II. Intertemporal Optimization, Growth Theory, and Discounting

A. Dynamic Optimization Using Optimal Control Theory
Conrad and Clark, chapter 1.
Kamien and Schwartz, Part II Optimal Control, Sections 1 - 4.

B. Growth Theory and Intertemporal Optimization
Blanchard, O. and S. Fischer. 1989. *Lectures on Macroeconomics*, chapter 2.
Malinvaud, E. 1953. Capital accumulation and efficient allocation of resources. *Econometrica* 21: 233-268.
Cass, D. 1965. Optimum growth in an aggregative model of capital accumulation. *Review of Economic Studies* 32(3): 233- 240.

C. Discounting
Ramsey, FP. 1928. A mathematical theory of saving. *Economic Journal* 38: 543–559.
Weitzman, M.L. 2001. Gamma Discounting. *American Economic Review* 91(1): 260-71.
Frederick, S., G. Loewenstein and T. O'Donaghue. 2002. Time discounting and preferences: A critical review. *Journal of Economic Literature* 4: 351-401.
Arrow, K.J., M.L. Cropper, C. Gollier, B. Groom, G.M. Heal, R.G. Newell, W.D. Nordhaus, R.S. Pindyck, W.A. Pizer, P.R. Portney, T. Sterner, R.S.J. Tol and M.L. Weitzman. 2014. Should governments use a declining discount rate in project analysis? *Review of Environmental Economics and Policy* 8(2): 145-163.
Lind, R.C. et al. 1982. *Discounting for Time and Risk in Energy Policy*. Resources for the Future.

Loewenstein, G. and J. Elster (eds.). 1992. *Choice over Time*. Russell Sage Foundation.

III. Renewable Resources

A. Bioeconomic Models of Fisheries and Optimal Harvesting

Clark, chapters 1-4, 7.
Conrad and Clark, chapter 2.
Hanley, Shogren and White, chapter 10.
Hartwick and Olewiler, chapter 11.
Wilen, J. 1985. Bioeconomics of renewable resource use, in Kneese and Sweeney (Eds.), *Handbook of Natural Resource Economics* Vol. 1.
Scott, A. 1955. The fishery: The objective of sole ownership, *Journal of Political Economy* 63: 116-124.
Clark, C. 1973. Profit maximization and the extinction of animal species. *Journal of Political Economy* 81: 950-961.
Berck, P. 1981. Optimal management of renewable resources with growing demand for stock externalities. *Journal of Environmental Economics and Management* 8(2):105-17.
Clark, C., F. Clarke, and G. Munro. 1979. The optimal exploitation of renewable resource stocks: Some problems of irreversible investment. *Econometrica* 47: 25-47.
Burt, O. 1964. Optimal resource use over time with an application to ground water. *Management Science* 11: 80-93.
Zhang, J. and M. Smith. 2011. Estimation of a generalized fishery model: A two-stage approach. *Review of Economics and Statistics* 93(2): 690–699.

B. Open Access

Clark, chapter 8.
Gordon, H.S. 1954. The economic theory of a common property resource: The fishery. *Journal of Political Economy* 62: 124-142.
Hardin, G. 1968. The tragedy of the commons. *Science* 162: 1243-1248. Smith, V. 1968. Economics of production from natural resources. *American Economic Review* 58: 409-431.
Smith. V. 1968. Economics of production from natural resources. *American Economic Review* 61: 488-491.
Gisser, M. and D. Sanchez. 1980. Competition versus optimal control in groundwater pumping. *Water Resources Research* 16: 638-642.
Brander, J. and M.S. Taylor. 1998. The simple economics of Easter Island: A Ricardo-Malthus model of renewable resource use. *American Economic Review* 88: 119-138.
Kremer, M. and C. Morcom. 2000. Elephants. *American Economic Review* 90: 212-234.
Taylor, M.S. 2011. Buffalo hunt: International trade and the virtual extinction of the North American Bison. *American Economic Review* 101: 362-395.

C. Regulating Access to Common Property Resources

Homans, F. and J. Wilen. 1997. A model of regulated open access resource use. *Journal of Environmental Economics and Management* 32: 1-21.
Beddington, J., D. Agnew, and C. Clark. 2007. Current problems in the management of marine fisheries. *Science* 316: 1713-1716.
Bohn, H. and R.T. Deacon. 2000. Ownership risk, investment, and the use of natural resources.

American Economic Review 90(3): 526-549.
Costello, C. J. and D. Kaffine. 2008. Natural resource use with limited-tenure property rights. *Journal of Environmental Economics and Management 55*(1): 20-36.
Costello, C., S. Gaines and J. Lynham. 2008. Can catch shares prevent fisheries collapse? *Science* 321: 1678-1681.
Johnson, R.N. and G.D. Libecap. 1982. Contracting problems and regulation: The case of the fishery. *American Economic Review* 72(5): 1005-1022.
Grainger, C.A. and C.J. Costello. 2014. Capitalizing property rights insecurity in natural resource assets. *Journal of Environmental Economics and Management 67*(2): 224-240.
Provencher, B. and O. Burt. 1993. The externalities associated with the common property exploitation of groundwater. *Journal of Environmental Economics and Managemen*t 24(2): 139–58.
Ostrom, E. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action*.

D. Game Theoretic Models of Common Property Resources

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.
Reinganum, J. and N. Stokey. 1985. Oligopoly extraction of a common property natural resource: The importance of the period of commitment in dynamic games. *International Economic Review* 26: 161-173.
Mason, C. and S. Polasky. 1994. Entry deterrence in the commons. *International Economic Review* 35: 507-525.
Sethi, R. and E. Somanathan. 1996. The evolution of social norms in common property resource use. *American Economic Review* 86(4); 766-788.
Dutta, P. 1995. Collusion, discounting and dynamic games. *Journal of Economic Theory* 66: 289-306.
Polasky, S., N. Tarui, G. Ellis and C. Mason. 2006. Cooperation in the commons. *Economic Theory* 29: 71-89.
Huang, L. and M. Smith. 2014. The dynamic resource costs of common-pool resource extraction. *American Economic Review* 104(12): 4071–4103.

E. Forestry: Age Dependent Growth and Timing of Harvest

Clark, chapter 9.
Hanley, Shogren and White, chapter 11.
Hartwick and Olewiler, chapter 10.
Samuelson, P. 1976. Economics of forestry in an evolving society, *Economic Inquiry* 14: 466-492.
Hartman, R. 1976. The harvesting decision when a standing forest has value. *Economic Inquiry* 14: 52-58.
Tahvonen, O. 2015. Economics of naturally regenerating, heterogeneous forests. *Journal of the Association of Environmental and Resource Economists* 2(2): 309-337.
Reed, W. 1986. Optimal harvesting models in forestry management - A survey. *Natural Resource Modeling* 1: 55-79.

F. Spatially Explicit Harvest Models

Sanchirico, J. and J. Wilen. 1999. Bioeconomics of spatial exploitation in a patchy environment. *Journal of Environmental Economics and Management* 37: 129-150.
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.
Smith, M.D. and J.E. Wilen. 2003. Economic impacts of marine reserves: The importance of spatial behavior. *Journal of Environmental Economics and Management 46*(2): 183-206.
Smith, M.D., 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.
Swallow, S.K. and D.N. Wear. 1993. Spatial interactions in multiple-use forestry and substitution and wealth effects for the single stand. *Journal of Environmental Economics and Management* 25(2):103-20.
Brozović, N., D.L. Sunding, and D. Zilberman. 2010. On the spatial nature of the groundwater pumping externality. *Resource and Energy Economics* 32(2): 154–64.
Edwards, E.C., 2016. What lies beneath? Aquifer heterogeneity and the economics of groundwater management. *Journal of the Association of Environmental and Resource Economists* 3(2): 453-491.

G. Renewable Resource Management with Uncertainty

Clark, chapter 11.
Conrad and Clark, chapter 5.
Mangel, M. 1985. *Decision and Control in Uncertain Resource Systems*.
Reed, W. 1979. Optimal escapement levels in stochastic and deterministic harvesting models, *Journal of Environmental Economics and Management* 6: 350-363.
Costello, C. and S. Polasky. 2008. Optimal harvesting of stochastic spatial resources. *Journal of Environmental Economics and Management* 56(1): 1-18.
Clark, C. and G. Kirkwood. 1986. On uncertain renewable resource stocks: Optimal harvest policies and the value of stock surveys. *Journal of Environmental Economics and Management* 13: 235-244.
Costello, C., S. Polasky and A. Solow. 2001. Renewable resource management with environmental prediction. *Canadian Journal of Economics* 34(1): 196-211.
Weitzman, M.L. 2002. Landing fees vs harvest quotas with uncertain fish stocks. *Journal of Environmental Economics and Management* 43:325-38.
Tsur, Y. and T. Graham-Tomasi. 1991. The buffer value of groundwater with stochastic surface water supplies. *Journal of Environmental Economics and Management* 21: 210-224.

H. Regime Shift

Scheffer, M., S. R. Carpenter, J. A. Foley, C. Folke and B.Walker. 2001. Catastrophic shifts in ecosystems. *Nature* 413: 591-596.
Reed, W. 1984. The effects of fire on the optimal rotation of a forest. *Journal of Environmental Economics and Management* 11: 180-190.
Reed, W.J. and H. Echavarria Heras. 1992. The conservation and exploitation of vulnerable resources. *Bulletin of Mathematical Biology* 54: 185-207.
Cropper, M. 1976. Regulating activities with catastrophic environmental effects. *Journal of Environmental Economics and Management* 3: 1-15.
Tsur, Y. and A. Zemel. 1995. Uncertainty and irreversibility in groundwater management. *Journal of Environmental Economics and Management* 29: 149–161.
Peterson, G., W. Brock, and S. Carpenter. 2003. Uncertainty and the management of multistate ecosystems: An apparently rational route to collapse. *Ecology* 84(6): 1403-1411.
Polasky, S., A. de Zeeuw, and F. Wagener. 2011. Optimal management with potential regime shifts. *Journal of Environmental Economics and Management* 62: 229-240.

I. Irreversibility, Uncertainty, and Option Value

Dixit and Pindyck, chapter 2 and chapter 4, pp. 93-103.
Conrad and Clark, chapter 5, sections 5.1 and 5.7.
Krutilla, J.V. and A.C. Fisher. 1975. *The Economics of Natural Environments: Studies in the Valuation of Commodity and Amenity Resources.*
Pindyck, R. 1991. Irreversibility, uncertainty, and investment. *Journal of Economic Literature*: 1110-1148.
Dixit, A. 1992. Investment and Hysteresis. *Journal of Economic Perspectives*: 107-132.
Krutilla, J. 1967. Conservation reconsidered. *American Economic Review* 47: 777-786.
Arrow, K. and A. Fisher. 1974. Environmental preservation, uncertainty, and Irreversibility. *Quarterly Journal of Economics* 88: 312-319.
Hanemann, W. M. 1989. Information and the concept of option value. *Journal of Environmental Economics and Management* 16: 23-37.

IV. Non-Renewable Resources

A. The Basic Hotelling Model and Extensions

Conrad and Clark, chapter 3.
Dasgupta and Heal, chapter 6.
Hanley, Shogren and White, chapter 9.
Hartwick and Olewiler, chapter 8.
Hartwick, J. 1989. *Non-Renewable Resources: Extraction Programs and Markets.*
Hotelling, H. 1931. The economics of exhaustible resources, *Journal of Political Economy* 39: 137-175.
Gray, L. 1914. Rent under the assumptions of exhaustibility. *Quarterly Journal of Economics* 28: 466-489.
Solow, R. 1974. The economics of resources or the resources of economics. *American Economic Review* 64:1-14.
Anderson, S.T., R. Kellogg and S. Salant. 2014. Hotelling under pressure. NBER Working Paper 20280.
Venables, A.J. 2014. Depletion and development: Natural resource supply with endogenous field opening. *Journal of the Association of Environmental and Resource Economists* 1(3): 313-336.
Levhari, D. and N. Liviatan. 1977. Notes on Hotelling's economics of exhaustible resources. *Canadian Journal of Economics* 10: 177-192.
Hartwick, J. 1978. Exploitation of many deposits of an exhaustible resource. *Econometrica* 46: 201-217.
Eswaran, M., T. Lewis, and T. Heaps.1983. On the nonexistence of market equilibria in exhaustible resources with decreasing costs. *Journal of Political Economy* 91: 154-167.
Heal, G. 1976. The relationship between price and extraction cost for a resource with a backstop technology. *Bell Journal of Economics* 7(2): 371-78.
Farzin, H. 1984. The effect of the discount rate on depletion of exhaustible resources. *Journal of Political Economy* 92: 841-851.
Gaudet, G., M. Moreau and S. Salant. 2001. Intertemporal depletion of resource sites by spatially distributed users. *American Economic Review* 91: 1149-1159.

B. Non-renewable Resources, Capital, and Growth Theory

Dasgupta and Heal, chapters 7 – 8.

Solow, R. 1974. On the intergenerational allocation of resources. *Review of Economic Studies* (Symposium): 29-45.

Stiglitz, J. 1974. Growth with exhaustible natural resources: Efficient and optimal growth paths. *Review of Economic Studies* (Symposium): 123-137.

Hartwick, J. 1977. Intergenerational equity and the investing of rents from exhaustible resources. *American Economic Review* 66: 972-974.

Lin, C., and G. Wagner. 2007. Steady-state growth in a Hotelling model of resource extraction. *Journal of Environmental Economics and Management* 54: 68–83.

C. Empirical Tests

Barnett, H.J. and C. Morse. 1963. *Scarcity and Growth: The Economics of Natural Resource Availability*. Johns Hopkins University Press.

Slade, M. 1982. Trends in natural-resource commodity prices: An analysis of the time domain. *Journal of Environmental Economics and Management* 9: 122-137.

Smith, V.K. 1980. The evaluation of natural resource adequacy: Elusive quest or frontier of economic analysis?" *Land Economics* 56: 257-298.

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.

Halvorsen, R. and T. Smith. 1991. A test of the theory of exhaustible resources. *Quarterly Journal of Economics*, 123-140.

Livernois, J. 2009. On the empirical significance of the Hotelling Rule. *Review of Environmental Economics and Policy* 3: 22-41.

D. Oil Prices

Smith, J.L. 2009. World oil: Market or mayhem? *Journal of Economic Perspectives* 23(3):145–164.

Hamilton, J.D., 2009. Causes and consequences of the oil shock of 2007–08. *Brookings Papers on Economic Activity* 1: 215–61.

Kilian, L. and D.P. Murphy. 2014. The role of inventories and speculative trading in the global market for crude oil. *Journal of Applied Econometrics* 29(3): 454–78.

Knittel, C.R. and R.S. Pindyck. 2016. The simple economics of commodity price speculation. *American Economic Journal: Macroeconomics* 8(2): 85-110.

Baumeister, C., and L. Killian. Understanding the decline in the price of oil since June 2014. *Journal of the Association of Environmental and Resource Economists* 3(1): 131-158.

E. Exploration and Uncertainty

Pindyck, R. 1978. The optimal exploration and production of nonrenewable resources. *Journal of Political Economy* 86: 841-861.

Loury, G. 1978. The optimal exploitation of an unknown reserve. *Review of Economic Studies* 45: 621-636.

Arrow, K. and S. Chang. 1982. Optimal pricing, use and exploration of uncertain natural resource stocks. *Journal of Environmental Economics and Management* 9: 1-10.

Polasky, S. 1992. The private and social value of information: Exploration for exhaustible resources. *Journal of Environmental Economics and Management* 23: 1-21.

F. Imperfect Competition

Hartwick and Olewiler, chapter 9.

Karp, L. and D. Newbery. 1993. Intertemporal consistency issues in depletable resources. In Knesse and Sweeney (Ed.) *Handbook of Natural Resource and Energy Economics*, Vol. III.

Stiglitz, J. 1976. Monopoly and the rate of extraction of exhaustible resources. *American Economic Review* 66: 655-661.

Salant, S. 1976. Exhaustible resource and industrial structure: A Nash-Cournot approach to the 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.

Loury, G. 1986. A theory of 'oil'igopoly: Cournot equiblirum in exhaustible resource markets with fixed supplies. *International Economic Review* 27: 285-301.

Polasky, S. 1992. Do oil producers act as 'oil'igopolists?" *Journal of Environmental Economics and Management* 23: 216-247.

V. Biodiversity and Ecosystem Services

A. Biodiversity Measures and the Value of Biodiversity

Polasky, S., C. Costello and A. Solow. 2005. The economics of biodiversity. In *The Handbook of Environmental Economics, Vol. 3*, J. Vincent and K.-G. Maler (eds.). Elsevier – North Holland.

Weitzman. M. 1992. On diversity, *Quarterly Journal of Economics* 107(2): 363-405.

Solow, A. and S. Polasky. 1994. Measuring biological diversity, *Environmental and Ecological Statistics* 1(2): 95-107.

Brock. W. and A. Xepapadaes. 2003. Valuing biodiversity from an economic perspective: A unified economic, ecological and genetic approach, *American Economic Review* 93(5): 1597-1614

Tilman, D., S. Polasky and C. Lehman. 2005. Diversity, productivity and temporal stability in the economies of humans and nature. *Journal of Environmental Economics and Management* 49(3): 405-426.

B. Strategies to Conserve Biodiversity

Montgomery, C., G. Brown and D. Adams. 1994. The marginal cost of species preservation: The case of the Northern Spotted Owl. *Journal of Environmental Economics and Management* 26: 111-128.

Ando, A., J. Camm, S. Polasky and A. Solow. 1998. Species distributions, land values and efficient conservation. *Science* 279: 2126-2128.

Weitzman. M.L. 1998. The Noah's Ark problem. *Econometrica* 66: 1279-1298.

Montgomery, C., R. Pollak, K. Freemark and D. White. 1999. Pricing biodiversity. *Journal of Environmental Economics and Management* 38: 1-19.

Wilson, K.A., M. R. McBride, M. Bode and H.P. Possingham. 2006. Prioritizing global conservation efforts. *Nature* 440: 337-340.

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