Class: ARE 298, Dynamic Modeling
Instructor: Christian Traeger
Time: March 30st-April 10th
Mo-Th: 8-10am & 4-6pm
Fr.: 8-10am & 2-4pm
Mo, We, Th: discussion hours fixed in class
Location: Giannini 234

1. **Prerequisite:**
A graduate level exposure to calculus-based economic modeling and some basic experience in programming will prove helpful. The class is open to any student who considers himself in the position to acquire the skillset lined out below. Please consult with me in person if you are uncertain whether the class is appropriate for you given your personal background.

2. **Course content:**
The course helps you to build an economic model to analyze your research questions. The focus lies on dynamic modeling, but we start with general considerations and static models. We cover both analytic and numeric modeling tools and discuss their advantages and disadvantages. The topical focus is on environmental economics and climate change.

3. **Method of instruction:**
The morning classes focus on introducing general ideas, formalisms, and tools. The afternoon classes focus on applications and numeric implementations of algorithms.

4. **Class outline**

Block		Morning	Afternoon
1	Mo 30	How to build an economic model?	Discussion of research topics Optimizing in Matlab
2	Tu 31	Function approximation	Numeric application
3	We 1	Modeling uncertainty	Applications (analytic and numeric)
3	Th 2	Two period models	Discussion of research projects
4	Fr 3	Dynamic Programming (∞ horizon)	Numeric application
4	Mo 6	Dynamic Programming (advanced)	Numeric application
5	Tu 7	Optimal Control	Preliminary project presentations
5/6	We 8	Optimal Control Non-convex control problems	Application (numeric and/or analytic)
7	Th 9	Integrated Assessment of Climate Change (introduction, sensitivities)	Applications (numeric and/or analytic)
7	Fr 10	Integrated Assessment of Climate Change (analytic models)	Final project presentations

5. **Learning objectives: Ability to**
    - Translate research questions into an economic model
    - Reflect on the (dis-)advantages of simplicity and generality in economics models
    - Build analytic and numeric models (deterministic, uncertain, dynamic)
    - Analyze policy through the lens of economic models
    - Understand policy implications of dynamic interactions using shadow values and value functions
    - Understand how uncertainty affects optimal policy
    - Differentiate between smooth and non-convex phenomena and their policy implications
    - Understand and build integrated assessment models of climate change

6. **Programming language:** I encourage the use of MATLAB for the numeric applications because I will provide some code and help in MATLAB. If you have a strong background in another programming language such as, e.g., Python or Julia you are welcome to use it.

7. **Preparation for class**:

    - Please read the "Programming Background for ARE 298" document. Follow the instructions to install Matlab and the COMPECON toolbox on your computer, and watch the suggested videos if you are not yet familiar with the Matlab programming language. Please apply for the Matlab license in time before March 30st, and have the programs installed for use in time for the first afternoon class on March 30st.
    - Please read one of the articles in block #1 before the morning class on March 30st. In particular, I recommend that you read Varian's "How to Build an Economic Model in Your Spare Time" not just for class but more generally for advice on research and writing a paper.

8. **Course requirements and grading:** The main requirement is the "student project" in which you take your own research question and translate it into a model that you solve either analytically or numerically. This model has to be dynamic. We will discuss your project partly in office hours and partly in class. In addition, we will have problem sets that you solve partly at home and partly in the afternoon/evening classes. The course grade will be based on your project (45%), the problem sets (35%), and your class participation (20%).

Useful books:

The lecture does not follow any book in particular. The book most closely related to the lecture is the first in the below list by Mario Miranda and Paul Fackler. In particular, several numeric applications relate to the book and rely on their COMPECON toolbox. The second book by John Stachurski contains a more rigorous treatment of dynamic programming and provides exemplary code in both Python and Matlab. The third book by Kenneth Judd is an in depth treatment of numerical methods with less of a focus on dynamic applications. The forth book by Kamien and Schwartz is a classic on analytic dynamic optimization, introducing both dynamic programming and optimal control. The fifth book by Alpha Chiang contains a simpler introduction to optimal control (and some mistakes).

Most useful books:

- Applied Computational Economics and Finance, Mario Miranda and Paul Fackler, MIT Press, 2002
- Economic Dynamics: Theory and Computation, John Stachurski, MIT Press, 2009.
- Numerical Methods in Economics, Kenneth Judd, MIT Press 1999.
- Dynamic Optimization, any edition, M Kamien and N Schwartz, North Holland 2003.
- Elements of Dynamic Optimization, Alpha Chiang, McGraw Hill 1999.

In addition, I have a book draft on my website on "Dynamic Methods in Environmental and Resource Economics" by Larry Karp and myself that covers many of the topics we analyze in class. The following books offer more advanced treatments of topics related to class.

Other books:

- Seierstad and Sydsæter. *Optimal Control Theory with Economic Applications,* North-Holland, 1987.
- Dynamic Programming and Optimal Control, D Bertsekas, Athena Scientific Press 1995.
- Recursive Methods in Economic Dynamics, Stokey and Lucas, Harvard University Press, 1989.
- Investment under Uncertainty, Dixit and Pindyck, Princeton University Press, 1994.
- Differential Games in Economics and Management Science, Dockner, van Long and Sorger, Cambridge University Press 2000, (chapter 3 is a nice introduction to continuous time dynamic programming)

Reading Material by Block:

1. **How to build an economic model**
   Varian, Hal R. (2009), How to Build an Economic Model in Your Spare Time.
   The Economist (2010), Building better models (Free Exchange).
   Gruene-Yanoff, T. (2009), Learning from minimal economic models, Erkenntnis 70:81-99.

2. **Function approximation:**
   Miranda and Fackler (2002), chapter 6, in particular, 6.1-3 & 6.6-8.
   Karp & Traeger (2013), chapter 7.2. & 7.4.

3. **Uncertainty & Two period models**
   Relies very much on the lecture and my blackboard presentation of the material. Related readings include (none of which covers well the composition of class material):

   - Karp & Traeger (2013), chapter 4.
   - L. Eeckhoudt and H. Schlesinger. "Putting Risk in Its Proper Place." *American Economic Review*, Vol. 96 (2006), pp. 280-289.
   - Dixit & Pindyck (1994), chapters 1-2.
   - R.S. Pindyck. "Uncertainty in Environmental Economics." *Review of Environmental Economics and Policy,* Vol. 1 (2007), pp. 45-65.
   - Lange and Treich (2008), Uncertainty, learning and ambiguity in economic models on climate policy: some classical results and new directions, Climatic Change 89:7–21.
   - C. Traeger (2009): Recent Developments in the Intertemporal Modeling of Uncertainty. Annual Review of Resource Economics 2009. 1:261-85.

4. **Dynamic Programming**
   Miranda & Fackler (2002), chapters 7-9.
   Karp & Traeger (2013), chapter 1,3,7.

5. **Optimal Control**
   Karp & Traeger (2013), chapter 9.
   Chiang (1999), chapters 7-9.
   Kamien and Schwartz, part II, sections 1 - 9

6. **Nonconvex-control**
   Karp & Traeger (2013), chapter 13.
   Original articles underlying the shallow lake application:

   - Dasgupta and Maler (2003), The Economics of Non-Convex Ecosystems: Introduction, Environmental and Resource Economics 26: 499–525.
   - Brock and Starrett (2003), Managing Systems with Non-convex Positive Feedback, Environmental and Resource Economics 26: 575–602.
   - Mäler, Xepapadeas and de Zeeuw (2003), The Economics of Shallow Lakes, Environmental and Resource Economics 26: 603–624.

7. Integrated Assessment of Climate Change

- W.D. Nordhaus. *A Question of Balance: Weighing the Options on Global Warming Policies,* Yale University Press, New Haven, CT, 2008.
- Golosov, Hassler, Krusell, Tryvinki (2014). "Optimal Taxes on Fossil Fuels in General Equilibrium", Econometrica 82: 41-88.
- Traeger, C. (2015), "Analytic Integrated Assessment and Uncertainty", see homepage.
- R. Gerlagh and M. Liski (2012), "Carbon Prices for the Next Thousand Years", CESifo Working Paper Series No. 3855
- Hassler, J. and P. Krusell (2012), "Economics and climate change - integrated assessment in a multi-region world", Journal of the European Economic Association 10:974–1000.
- Kelly and Kolstad (1999), Bayesian learning, growth, and pollution, Journal of Economic Dynamics and Control, 23: 491-518.
- Hoel and Karp (2002), Taxes versus quotas for a stock pollutant, Resource and Energy Economcis 24: 367-384.
- Karp and Zhang (2005), Regulation with Anticipated Learning about Environmental Damages, Journal of Environmental Economics and Management 51: 259–279.
- L. Karp (2012), "Provision of a public good with altruistic overlapping generations and many tribes", see homepage Karp.
- Lemoine, D. and C.P. Traeger (2014), Watch Your Step: Optimal Policy in a Tipping Climate, American Economic Journal: Economic Policy 6(1): 1–31.
- M.L. Weitzman. "On Modeling and Interpreting the Economics of Catastrophic Climate Change," Review of Economics and Statistics: 91(1) (2009), pp. 1–19.
- Martin, I.W.R. and R.S. Pindyck (2014), Averting Catastrophes: The Strange Economics of Scylla and Charybdis," NBER Working Papers 20215
- Jensen, S. and C.P. Traeger (2014), Optimal Climate Change Mitigation under Long-Term Growth Uncertainty: Stochastic Integrated Assessment and Analytic Findings, European Economic Review 69(C): 104-125.
- Anderson, E., Brock, W., Hansen, L. P. & Sanstad, A. H. (2014), 'Robust analytical and computational explorations of coupled economic-climate models with carbon-climate response', RDCEP Working Paper No.13-05.
- IPCC. "Climate Change 2007: The Physical Science Basis," Summary for Policymakers. *Fourth Assessment Report of the United Nations Intergovernmental Panel on Climate Change*, Working Group I, 2007a.
- IPCC. "Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability," Summary for Policymakers. *Fourth Assessment Report of the United Nations Intergovernmental Panel on Climate Change*, Working Group II, 2007b.
- C.D. Kolstad and M. Toman. "The Economics of Climate Policy." In Mäler and Vincent (eds.) *Handbook of Environmental Economics*, Vol. 3, Elsevier, 2005, Chapter 30, Section 2: Overview of the Climate Change Issue.
- N. Stern et al. "Stern Review on the Economics of Climate Change." HM Treasury, 2007.
- Online Sources on Different Integrated Assessment Models:
  - DICE: http://www.econ.yale.edu/~nordhaus/homepage/index.html
  - FUND: http://www.fund-model.org/
  - WITCH: http://www.witchmodel.org/pag/model.html
  - Model survey: http://www.metasd.com/ModelSurvey.xml