APPLIED GENERAL EQUILIBRIUM ANALYSIS
FALL SEMESTER, 2023

Instructors:
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Course time: This class is offered as a partially 'flipped classroom' so core lectures and lab assignments are offered over the web. Lab assignments are due by Saturday at 12 midnight. *Weekly class discussions take place on Monday from 10:30-11:20am in Rawls 1071. Guest lectures will take place on Wednesday from 10:30-11:20am in Rawls 1071.*

Office hours:
Wednesday, 4:00 – 5:00 pm, as well as other times by appointment (use email to make appointments). Questions and discussions on *Brightspace* are strongly encouraged.

Intended Audience:
PhD students (and exceptional MS students with a strong foundation in micro-economics), with an interest in the quantitative analysis of economy-wide issues relating to public policy, marketing and international trade, economic development, resources, technology and the environment.

Prerequisites:
Graduate level microeconomics with a strong foundation in consumer and producer theory.

Readings:
All readings will be available on-line, through *Brightspace.*

Software:

Pearson, K., Horridge, M., & Corong, E. (2018). *Hands-on Computing with RunGTAP and WinGEM To Introduce GTAP and GEMPACK* (Center of Policies Studies). Purdue University, West Lafayette, IN: Global Trade Analysis Project (GTAP). Retrieved from https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=1638

Horridge J.M., Jerie M., Mustakinov D. & Schiffmann F. (2019), *GEMPACK manual*, GEMPACK Software, ISBN 978-1-921654-90-9. Available at https://www.copsmodels.com/gpmanual.htm

Grading:

Weekly Homework (50% of grade) – These generally take 2-3 hours to complete and they are submitted electronically on a weekly basis. They comprise the core of the coursework.

Midterm Exam (10% of grade). The purpose of this take-home exam is to ensure that you have absorbed the key lessons of the weekly assignments during the first seven weeks. We will build on this core material in the second half of the course.

Individual presentation and write-up of special project (40% of grade). This is the 'main event'. In consultation with the instructors, you will choose a topic, thereupon replicating, critiquing and extending an existing study. You will present your findings during the final week of class. *For a list of studies available for replication, please refer to the Potential Applications List.*

Course Description:

This course has two objectives. First, and foremost, the course seeks to *provide students with a conceptual framework for looking at issues from an economy-wide perspective*. It is hoped that this will remain with participants *regardless of whether they choose to conduct their own applied general equilibrium (AGE) analyses in the future*. This is accomplished via a set of lectures, relevant readings, homework assignments, and structured computer simulation exercises. These are designed to provide insights into the basic mechanisms and key parameters that determine inter-sectoral linkages in the global economy. They are also structured in a way that emphasizes connections to the literature in production, consumption, marketing, trade, resources, welfare and environmental economics. As such, it often helps students to conceptualize the connections between some of their other, more specialized, coursework.

The other objective of this course is to *expose participants to an operational framework* (including theory, software and data) *for conducting global AGE analysis*, which they can draw upon in future research efforts. This framework will be highlighted through a series of guest lectures as well as through the homework exercises. Participants will exercise this framework in the context of a class project to be written up and presented to the class at the end of the semester. This project will involve replication of an existing applied general equilibrium application, followed by an agreed-upon, extension of the published work.

The computer assignments and the course project will all be implemented in the context of the *RunGTAP* software interface (Pearson, Horridge, Corong 2018) to GEMPACK. This is a Windows environment for conducting applied general equilibrium analysis with the Global Trade Analysis Project (GTAP) model, designed to allow users to focus on economics with the programming details being largely taken care of behind the scenes. The use of this tool has sharply reduced the time required to get participants "up to speed" on the software front. RunGTAP runs *GEMPACK* programs "behind the scenes". *GEMPACK* is an algebraic modeling language (similar to GAMS) that permits the user to write out the model in a transparent fashion. It is specifically designed for application to large-scale partial and general equilibrium models in a policy-oriented environment. Students will become expert users of the analytical tools, but the design of the course is such that they will not need to become expert programmers in GEMPACK. This year, we will, however, offer students some additional background in GEMPACK so they can modify existing models/applications if desired.

The GTAP Data Base, and associated tools, which we will use in this course are amenable to a wide range of applications. It is currently in use by a network of more than 26,000 researchers in 175+ countries. Many of the leading national and international policy-oriented agencies use it, including: the World Bank, the WTO, the UN Conference on Trade and Development, the European Commission, the US International Trade Commission, and the US Departments of Agriculture, Commerce, Energy and Environmental Protection, along with private sector consultancies such as McKinsey & Co. and KPMG. *There is an active market for graduates with GTAP-based skills, as all of these organizations hire PhD economists to work on the topics covered in this course.* Current GTAP applications span a wide range of areas, including: trade policy, regional economic integration, resource and environmental economics, impacts of technological progress, climate change impacts and mitigation, and international migration. There is a searchable database of GTAP applications on the web at: www.gtap.org .

Course Requirements
The central tool for learning in this course will be *weekly homework assignments* during the first nine weeks of the course, designed to reinforce the material covered in the lectures. In the second part of the semester, the focus turns to advanced topics as well as *class projects*. These projects will involve the replication of an existing, published study, thereupon extending it in some meaningful way. The final presentation and write-up of this work will be in lieu of a final exam.

Course Overview Week #: Main theme (covered on Monday by Hertel) / Guest Lecture *(covered on XX/YY- – generally Wednesday- by guest speaker)*

Part I: Introduction

- Week 1: *(08/21: Hertel)* Getting Started / OneGTAP & GEMPACK *(08/23: Corong)*

Part II: Closed Economy Analyses: Weeks 2-7

- Week 2: *(08/28: Hertel)* Overview of the Closed Economy Model / Linearization and interpretation of behavioral equations *(08/30: Wang)*
- Week 3: *(09/06: Hertel)* Producer Behavior (Monday is Labor Day; no guest lecture; our sole meeting will be Wednesday 09/06)
- Week 4: *(09/11: Hertel)* Household Behavior / Derivation and calibration of key demand equations *(09/13: Wang)*
- Week 5: *(09/18: Hertel)* Aggregation across Agents and Market Responses / Modeling nutrition and food waste *(09/20: Chepeliev)*
- Week 6: *(09/25: Hertel)* Welfare Analysis in a Second-best Setting / Modeling energy use *(09/27: Golub)*
- Week 7: Take home exam: *No class meeting Monday* / The Economic contribution of nature-based services *(10/04: Baldos)*

Part III: Open Economy Analysis: Weeks 8-9

- Week 8: October Break *(no meeting Monday)*, followed by Introduction to the Multi-region model in Wednesday class *(10/11: Hertel)*
- Week 9: *(10/16: Hertel)* Global Sectors, Macroeconomic Closure, and Welfare Decomposition / Overview of GTAP 11 data base and model extensions *(10/18: Aguiar)*

Part IV: Extensions of the Standard Model: Weeks 10-12

- Week 10: Eaton-Kortum Model and application to trade policy *(10/23-25: Corong)*
- Week 11: Melitz Model – Introducing Firm Heterogeneity *(10/30-11/01: Akgul)*
- Week 12: Firm Heterogeneity in General Equilibrium *(11/06-08: Akgul)*

Part V: Climate Change: Weeks 13-14

- Week 13: Estimating the Economywide Impacts of Climate Change *(11/13-15: Hertel)*
- Week 14 Thanksgiving week – work on class projects
- Week 15: Integrated Climate Assessment and Mitigation Policy *(11/27-29: van der Mensbrugghe)*

Part VI: Synthesis and Presentations: Week 15

- Week 16: Student Presentations *12/04-12/06*

COURSE SYLLABUS

In the course outline that follows, each week's activities may involve eight different types of tools for learning. They are listed in the order in which we recommend they be done.

Lectures: These are both voice-over *PowerPoint* lectures, as well as lecture notes intended to be carefully read and digested. They are designed to introduce the topics of the week.

Illustrative simulation: This offers an opportunity to "get your hands dirty" with a simulation, before all of the material is covered. This can be a useful motivating factor for delving more deeply into the material.

Required Readings: Must be read.

Supplementary Readings: These are optional.

Homework: Homework assignments are due by Saturday noon. This gives us time to correct them so that we can discuss any weaknesses/challenge areas the following Monday. Check the course calendar on Brightspace for updates in case assignment due dates are changed.

Weekly Discussion: Each week there will be a session at which students can discuss the assignments, lectures and readings, as well as raising other issues. Ongoing discussion will be facilitated via Brightspace.

Guest Lectures: In order to expose participants to topical issues in applied general equilibrium modeling. These may also become the focus of a class project if participants choose to do so.

Special Project: During the second half of the semester, there will be weekly tasks associated with participants' special projects, culminating in presentation of their own extension of an existing study.

Part I: Introduction

Week 1. Getting Started

Lectures:
> Lecture 1: Introduction to AGE Analysis: Why General Equilibrium?
> Lecture 2: Motivation for Starting with a One-Region Model

Illustrative Simulation:
> Simulation 1: Introduction to RunGTAP for the One Region Model: OneGTAP Tutorial

Required Readings:
- Hertel, T. W., 2012. "Global Applied General Equilibrium Analysis using the GTAP Framework", in *The Handbook of Computable General Equilibrium Modeling*, edited by Peter Dixon and Dale Jorgenson, part of the Handbook of Economics Series from Elsevier Publishers.
- Hertel, Thomas W., 1990. "General Equilibrium Analysis of Agriculture: What Does It Contribute?" *Journal of Agricultural Economics Research*, Summer Issue, Vol. 42, No.3.

Homework:
> Assignment 1: Viewing of Database and Numeraire Simulation.

Part II: Closed Economy in General Equilibrium

Week 2. Overview of the Closed Economy Model
Lectures:
> Lecture 1: Overview of the Closed Economy, GTAP Framework
> Lecture 2: Accounting Relationships in the One Region Model
> Lecture 3: Price Linkage Relationships
> Lecture 4: Detailed Listing and Derivation of Accounting Equations
> Lecture 5: Tax/subsidy Conventions
> Lecture 6: Model equations
> Lecture 7: Detailed Listing and Derivation of Price Linkages

Illustrative Simulation:
> Simulation 1: Output Tax Shock: Viewing OneGTAP Output

Required Readings:
- Brockmeier, M. "A Graphical Exposition of the GTAP Model", sections 1 - 3, GTAP Technical Paper No.8, Center for Global Trade Analysis, Purdue University. This can be downloaded from: http://www.gtap.agecon.purdue.edu/resources/tech_papers.asp

Supplementary Readings:
Participants should read one of the following surveys of applied general equilibrium analysis to get a feel for how these models have been used in the past:

- Hertel, T., 2002. "Applied General Equilibrium Analysis of Agricultural and Resource Policies", Chapter 26 in *Handbook of Agricultural and Resource Economics*, edited by Bruce Gardner and Gordon Rausser, Amsterdam: North Holland Press.

- Robinson, S. 1998. "Multisectoral Models of Developing Countries: A Survey", *Handbook of Development Economics*, Chenery and Srinivasan, (eds.), Amsterdam: North Holland Press.

Homework
      Assignment 2: Proving Walras Law in the One Region Model

Week 3. Producer Behavior (Wednesday Class due to Labor Day)

Lectures:
      Lecture 1: Introduction to Producer Behavior
      Lecture 2: General and Particular Restrictions on a Production Function
      Lecture 3: Notes on the Restrictions on the Production Function
      Lecture 4: The Nested CES Production Function: Theory and a Specific Example
      Lecture 5: Notes on the CES Functional Form
      Lecture 6: A Specific Production Function

Illustrative Simulation:
      Simulation 1: Conditional (Output Constant) Producer Response to a Change in Input Price

Required Readings:
- Hertel, T. and M. Tsigas. 1997. "Structure of GTAP", chapter 2, pages 38-46, in *Global Trade Analysis: Modeling and Applications*, edited by Thomas W. Hertel. New York: Cambridge University Press, online at: https://www.gtap.agecon.purdue.edu/products/gtap_book.asp.

Supplementary Reading:
- Gohin, A. and T. Hertel. 2003. "*A Note on the CES Functional Form and Its Use in the GTAP Model*" GTAP Research Memorandum No. 02, Center for Global Trade Analysis, Purdue University, USA.

Homework
      Assignment 3: Producer Behavior – Conditional Elasticities of Demand

Week 4. Household Behavior

Lectures:
      Lecture 1: Overview of Final Demand
      Lecture 2: General and Particular Restrictions on Consumer Demand
      Lecture 3: Treatment of Government and Savings Demands
      Lecture 4: CDE Expenditure Function
      Lecture 5: Final Demand in the Presence of Non-homothetic Separability

Illustrative Simulation:
      Simulation 1: Household Response to a Price Change.
      Simulation 2: Introduction to AnalyseGE Software.

Required Readings:

- Hertel, T. and M. Tsigas. 1997. "Structure of GTAP", chapter 2, pages 46-51 and chapter 4, pages 133-147, in *Global Trade Analysis: Modeling and Applications*, edited by Thomas W. Hertel. New York: Cambridge University Press.

- Hertel, Thomas W. 2001. "Notes on Final Demand in the Presence of Non-homothetic, Weak Separability", Center for Global Trade Analysis, Purdue University (PDF from course website Module 4).

Supplementary Readings:
- McDougall, R.M. "A New Regional Household Demand System for GTAP," GTAP Working Paper no. 14, Center for Global Trade Analysis, Purdue University. This can be downloaded from: http://www.gtap.agecon.purdue.edu/resources/working_papers.asp

Homework
    Assignment 4: Analysis of Consumer Behavior

Week 5. Aggregation across Agents and Market Responses

Lectures:
    Lecture 1: Supply Response in the one region model
    Lecture 2: Notes on Supply Response
    Lecture 3: Market Demand
    Lecture 4: Equilibrium Demand Elasticities & Dalton's Law

Supplementary Lectures:
    Lecture 5: Links between AGE Analysis and input-output/Social Accounting Matrix based Analysis
    Lecture 6: Partial vs. General Equilibrium Closures

Illustrative Simulation:
    Simulation 1: Supply Response to a Change in Producer Prices
    Simulation 2: Market Demand Response to a Price Change

Required Readings:

- Hertel, Thomas W. 2011. "The Global Supply and Demand for Agricultural Land in 2050: A Perfect Storm in the Making?," *American Journal of Agricultural Economics*. Focus on the technical appendix and interpretation of equation (1) in the text. The appendix may be found here: https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=3428

Supplementary Readings:

- Keller, W.J. 1980. "Dalton's Law" chapter 3: in *Tax Incidence: A General Equilibrium Approach*. Sections 3.1-3.6, pp. 17-29, Amsterdam: North Holland Press.

Homework
    Assignment 5: Markets: General Equilibrium Incidence of an Output Subsidy

Week 6: Welfare Analysis in a Second-best Setting

Lectures:
> Lecture 1: Equivalent Variation as a Measure of Welfare Change
> Lecture 2: Welfare Decomposition

Illustrative Simulation:
> Simulation 1: Welfare Change due to an Output Tax

Required Readings:
- Huff and Hertel, 2002 "Decomposing Welfare Changes in the GTAP Model", GTAP Technical Paper #5, part 1, Center for Global Trade Analysis, Purdue University. This can be downloaded from: http://www.gtap.agecon.purdue.edu/resources/tech_papers.asp

Homework
> Assignment 6: Welfare Effects of a Manufactures Subsidy

Week 7: Take-home exam due Friday, Oct 8, at 12 noon, followed by Fall Break

> **Part III: Open Economy Analysis**

Week 8: Introduction to the Multi-Region model

Lectures:
> Lecture 1: Overview
> Lecture 2: Accounting Relationships
> Lecture 3: Price Linkages
> Lecture 4: Armington Structure
> Lecture 5: Summary of Model Equations

Supplementary Lectures:
> Lecture 6: Data Base Overview and Discussion of the Domestic Data Bases
> Lecture 7: Bilateral Merchandise Trade Data
> Lecture 8: Other International Data Sets

Required Readings:
- Brockmeier, M. "A Graphical Exposition of the GTAP Model", section 4, GTAP Technical Paper No. 8, Center for Global Trade Analysis, Purdue University. This can be downloaded from: http://www.gtap.agecon.purdue.edu/resources/tech_papers.asp

- Remainder of chapter 2 in GTAP book, also chapters 3 - 5.

Supplementary Readings:
- Aguiar, A.A., M. Chepeliev, E. Corong, D. van der Mensbrugghe. 2022. "The GTAP Data Base: Version 11", *Journal of Global Economic Analysis*, 6(2).

Homework
> Assignment 7: Exercises with Behavioral Equations

Week 9: Global Sectors, Macroeconomic Closure, and Welfare Decompositions

Lectures:

Lecture 1: Global Transport Sector
Lecture 2: Global Bank
Lecture 3: Multi-region Welfare and Terms of Trade Decomposition

Supplementary Lectures:
Lecture 4: International Transport Margins by Mode

Required Readings:
- Huff and Hertel, 1996 "Decomposing Welfare Changes in the GTAP Model", GTAP Technical Paper #5, part 2. http://www.gtap.agecon.purdue.edu/resources/tech_papers.asp

- McDougall, R.A. 1993. "Two Small Extensions to SALTER", SALTER Working Paper No. 12, Industry Commission: Canberra, Australia.

Homework
Assignment 8: Welfare Decomposition of a Trade Policy Shock

Part IV: Modern Trade Theory in AGE Models

Week 10: The Eaton-Kortum Ricardian Model of Trade

Lecture:
Lecture: Introduction to the EK Model

Required Readings:
- Eaton, J. and Kortum, S. (2002) "Technology, Geography, and Trade", *Econometrica*, 70, 1741-1779.

Supplementary Readings:

- Bekkers, E., Corong, E. and J. Francois (2023) TBD.

Week 11: Introduction to the Melitz Model

Lecture:
Lecture: Introduction to firm heterogeneity

Required Readings:
- Melitz, M. J. 2003. "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity," *Econometrica*, 71, 1695-1725.

Supplementary Readings:

- Bernard, Andrew B., et al. "Firms in International Trade." Journal of Economic Perspectives 21.3 (2007): 105-130.

Week 12: The Melitz Model in General Equilibrium

Lecture:
Lecture: Incorporating firm heterogeneity into a CGE model

Required Readings:
- Akgul, Z., N.B. Villoria and T.W. Hertel, (2016) "GTAP-HET: Introducing Firm Heterogeneity into the GTAP Model", *Journal of Global Economic Analysis*, (1):111-180

Supplementary Readings:
- Balistreri, E. J. and T. F. Rutherford, 2013. "Computing General Equilibrium Theories of Monopolistic Competition and Heterogeneous Firms," in *Handbook of Computable General Equilibrium Modeling*, ed. by P. B. Dixon, and D. W. Jorgenson. Vol. 1, 1513-1570.

Homework:
Assignment 9: Trade Policy Analysis in the presence of Firm Heterogeneity

Part V: Global Economic Analysis of Climate Change

Week 13: Assessing Climate Change Impacts in General Equilibrium

Required Reading:
- Baldos, Uris L.C., Thomas W. Hertel, and Frances Moore, (2019). "Understanding the Spatial Distribution of Welfare Impacts of Global Warming on Agriculture and its Drivers", *American Journal of Agricultural Economics* 101(5):1455–1472. https://doi.org/10.1093/ajae/aaz027
- Saeed, W., I. Haqiqi, Q. Kong, M. Huber, J. R. Buzan, S. Chonabayashi, K. Motohashi, and T. W. Hertel (2022). "The Poverty Impacts of Labor Heat Stress in West Africa Under a Warming Climate", *Earth's Future* https://doi.org/10.1029/2022EF002777

Supplementary Reading:
- Buzan, Jonathan, and Matthew Huber. 2020. "Moist Heat Stress on a Hotter Earth." *Annual Review of Earth and Planetary Sciences* 48: 1–30. https://doi.org/10.1146/annurev-earth-053018-060100.

Week 14: Introduction to Integrated Climate Assessment and Mitigation Policy

Required Readings:
- Nordhaus, 2014. "Estimates of the Social Cost of Carbon: Concepts and Results from the DICE-2013R Model," *Journal of the Association of Environmental and Resource Economics,* 1(1/2)273-312. DOI: 10.1086/676035.
- McDougall, R. and A Golub, 2009. "GTAP-E: A Revised Energy-Environmental Version of the GTAP Model", GTAP Research Memorandum No. 15, Center for Global Trade Analysis, Purdue University, https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=2959

Supplementary Reading:
- Blanford, G.J., E. Kriegler and M. Tavoni, 2014. "Harmonization vs. fragmentation: overview of climate policy scenarios in EMF27," *Climatic Change*, 123:383-396, DOI: 10.1007/s10584-013-0951-9

Part VI: Synthesis and Presentations

Week 15: Student Presentations, Synthesis and Course Wrap-up