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AGEC 596/528

Global Change and the Challenge of Sustainably Feeding a Growing Planet

(CRN 64842)

An interdisciplinary course at Purdue University

Offered by Thomas W. Hertel and Uris L.C. Baldos

Department of Agricultural Economics

Spring Semester, 2016

Tuesday/Thursday: 10:30 – 11:45am, KRAN G-7

Motivation

Since the 2007/2008 commodity crisis, there has been a convergence of interest in the global farm and food system and its contributions to feeding the world's population as well as to ensuring the environmental sustainability of the planet. This has underscored the vulnerability of the global food system to shocks from extreme weather events, energy and financial markets, as well as government interventions in the form of export bans and other measures designed to avoid domestic adjustment to global scarcity. We have learned that a "perfect storm" in which all these factors coincide can have a severe impact on the world's poor, as well as putting considerable pressure on the world's natural resource base. As we look ahead to the middle of this century, will the world's resource base be up to the task of meeting the diverse demands being placed on it? What will be the environmental impact of such demands?

The number of people which the world must feed is expected to increase by another 2 billion by 2050. When coupled with significant nutritional improvements for the 2.1 billion people currently living on less than $2/day, this translates into a very substantial rise in the demand for agricultural production. Over the past century, global agriculture has managed to offer a growing population an improved diet, primarily by increasing productivity on existing cropland. Can this feat be repeated in the next forty years? There are recent signs of slowing yield growth for key staple crops and public opposition to genetically modified crops has slowed growth in the application of promising biotechnology developments to food production in some parts of the world. In addition, the IPCC foresees climate change becomes a significant drag on future productivity growth. In this context, the growing use of biomass for energy generation has contributed to concerns about future food scarcity. Indeed, over a two year period from 2005/6 – 2007/8, ethanol production in the US accounted for roughly half of the increase in global cereals consumption. To compound matters, water, a key input into agricultural production, is becoming increasingly scarce in many parts of the world. Since irrigated agriculture accounts for 70% of all freshwater withdrawals worldwide and about 40% of world agricultural output, such water scarcity is likely to impinge on global food availability and cost.

In addition, agriculture and forestry are increasingly envisioned as key sectors for climate change mitigation policy – offering low cost, near term abatement of greenhouse gas emissions. Yet any serious attempt to curtail these agricultural emissions will involve changes in the way farming is conducted, as well as placing limits on the expansion of farming – particularly in the tropics, where most of the agricultural land conversion has come at the expense of forests. Limiting the conversion of forests to agricultural lands is also critical to preserving the planet's biodiversity. These factors will restrict the potential for agricultural expansion.

In light of these challenges facing the world's resource base, this course will explore the fundamental drivers behind drivers of change in the global food system and the interactions with environmental and food security over the first half of this century.

Course website

This year, we will upload all course materials, readings and lab assignments in the course website. Go to https://mygeohub.org/courses/AGEC_596. You need to create an account in order to access the class website

Textbook (e-book is free for Purdue Students via Purdue Libraries)

Hertel, Thomas W. and U.L.C. Baldos, 2016. Global Change and the Challenge of Sustainably Feeding a Growing Planet, New York: Springer. http://link.springer.com/book/10.1007%2F978-3-319-22662-0

Format for the class

This course has now been taught for four times: the first year was at Stanford University (joint with David Lobell), with three subsequent offerings at Purdue University. It is a 3 credit class, meeting twice a week for a full semester. The first meeting of each week will introduce a new dimension of global land use, food and environmental security. We will kick off the week's activities with a guest lecture, followed by student-led discussion of the week's readings. The second meeting of each week will emphasize the economics underpinning how this particular dimension of the problem affects the global food system, resource use, environmental quality and nutritional outcomes. This will be motivated by the lab assignments which students undertake. The lab assignments are based on the SIMPLE economic model of global agriculture (a Simplified International Model of agricultural Prices, Land use and the Environment). These lab assignments will allow students to obtain a hands-on assessment of the relative importance of the different forces bearing on the long run supply and demand for food and land resources, as well as the implications for food security and the environment. The capstone event in this course is the student project, which will involve the application of SIMPLE to a problem of the student's choosing. (See the end of this syllabus for a listing of previous topics.)

The structure of each week's module will be as follows:

First meeting of each week *(10:30 am - 11:45 am: Tuesday; Krannert G-7)*

1) 45 minute presentation on the weekly topic led by a faculty member
2) 30 minute student-led discussion of the week's readings

Second meeting of each week *(10:30 am - 11:45 am: Thursday; Krannert G-7)*

1) 30 minute presentation on the economic dimensions of the topic
2) 45 minute discussion of the lab assignment

Prerequisites

This is an interdisciplinary course. As such, there are few prerequisites. A prior course in economics will ensure an understanding of the basic aspects of supply, demand and economic equilibrium. A solid grasp of mathematics up to and including differential calculus is also essential to understand the labs. Prior experience with mathematical modeling is also a plus.

Grading

Grades will be based on three factors: lab assignments, the quality of student led discussions of readings (each student will be asked to submit two discussion questions in advance of the first meeting each week), and the final project, which will be the focal point of the second half of the semester. There is no exam in this course.

Week 1: Overview: Jan. 12 - Lecture by Tom Hertel

During this week we will obtain an overview of the issues involved in the long run evolution of agriculture and the challenges of sustainably feeding the world's growing population. In addition to a descriptive, historical perspective on the issue, we will lay out a stylized, analytical framework which highlights the economic mechanisms at work.

Required Readings:

"The 9 billion-people question: A special report on feeding the world", *The Economist*, February 26, 2011.

Navin Ramankutty, Jonathan A Foley, and Nicholas J Olejniczak, "People on the Land: Changes in Global Population and Croplands during the 20th Century," *AMBIO: A Journal of the Human Environment* (2002): 251-257

Text: Chapter 1: "Overview of Global Land Use, Food Security and the Environment"

Lab Discussion: *Introduction to the modelling software and overview on how to run and analyze the experiments using SIMPLE*

Week 2: Population and Income as drivers of global food demand: Jan. 19 Guest Lecture by Brigitte Waldorf, Professor of Agricultural Economics

During this week we will examine the impact of population and income growth on long run food demand. This debate traces its roots back to the classic publication by Thomas Malthus in 1888 in which he predicted that population would win the footrace between supply and demand for food. As population growth has slowed, the relative importance of dietary upgrading has increased. This is driven by rising per capita incomes. However, these richer diets are much more land-intensive, hence putting additional pressure on the global resource base. When scarcity arises, it is typically the low income households which experience significant reductions in food consumption in response to rising price. This response is important from the point of view of nutrition as well as the manner in which global supply and demand are balanced in the face of a limited resource base.

Required Readings:

Gerland, P., et al. "World population stabilization unlikely this century" *Science* 346, no. 6206: 234-237.

Lutz, W., W. Butz, S. KC, W. Sanderson and S. Scherbov. "9 billion or 11 billion: The research behind new population projections?" http://blog.iiasa.ac.at/2014/09/23/9-billion-or-11-billion-the-research-behind-new-population-projections/ .

Textbook: Chapter 2: "Population and Income as Drivers of Global Change"

Lab Assignment 1: *Simulate the impact on global and regional food demand in 2050 of varying population growth assumptions and the income responsiveness of demand for food.*

Week 3: Energy markets as a driver of global agriculture: Jan. 26 Guest Lecture by Wally Tyner, James & Lois Ackerman Professor of Agricultural Economics

Biofuels have emerged as an important new driver of the global farm and food system.. Production of so-called first generation biofuels, produced from maize, sugarcane and oilseeds, grew sharply over the past decade, and many authors suggest that this growth contributed significantly to the 2007-2008 commodity price boom. Second generation biofuels entail greater uncertainty, and typically don't draw directly on foodstuffs for feedstocks; however they could also place significant claims on the world's land resources. During this week we will examine the origins of the biofuel boom, future prospects, and the implications for sustainability and resource use.

Required Readings:

Tyner, Wallace E. (2008). "The US Ethanol and Biofuels Boom: Its Origins, Current Status and Future Prospects" *BioScience* (58)7:646-653.

Textbook: Chapter 8: "Biofuels as a Driver of Long Run Land Use Change"

Lab Assignment 2: *Simulate the impact of International Energy Agency projections of biofuels growth to 2035 under varying assumptions environmental policy, as well as alternative assumptions about the price responsiveness of the extensive and demand margins of economic behavior.*

Week 4: Yield Growth and Yield Gaps: Feb. 2: Guest Lecture by Mitch Tuinstra, Professor of Agronomy and Wickersham Chair of Excellence and Scientific Director, Plant Science and Education Pipeline

Over the past 50 years, three-quarters of agricultural output growth came from higher yields. Can this success story be repeated in the next 50 years? There are signs that yield growth is slowing significantly for some key crops. Is this due to underinvestment in technology? Or perhaps prices? Or is it due to approaching bio-physical limits? Another constraint will be the increasing attention being paid to nitrogen fertilizer runoff and its adverse environmental consequences. We also examine why yields are still so low in much of the world, and what it might take to allow farmers to close these yield gaps.

Required Readings:

R.A. Fischer, Derek Byerlee, and G.O. Edmeades (2014), Chapters 1 and 14 in *Crop Yields and Global Food Security,* "ACIAR, Canberra, Australia.

David B. Lobell, Kenneth G. Cassman, and Christopher B. Field, "Crop Yield Gaps: Their Importance, Magnitudes, and Causes," *Annual Review of Environment and Resources* 34, no. 1 (11, 2009): 179-204;

Textbook: Chapter 3: Sections 3.1-3.2: “Productivity Growth and Yields in the Global Crops Sector”

Lab Discussion: *Examine the combined impact of population growth, income growth and biofuels on global land use in the context of supply response.*

Week 5: Climate Change as a factor influencing global agriculture: Feb. 9 - Guest lecture by Keith Cherkauer, Associate Professor of Agricultural and Biological Engineering

The question of meeting global food, fiber and fuel demands in 2050 is greatly complicated by the prospect of climate change which is likely to alter temperature and precipitation as well as the frequency and intensity of extreme events. How will climate change affect land use? This will depend not only on the absolute impacts, but also on the relative impacts – the changes in comparative advantage of competing land using activities across regions of the world.

Required Readings:

Choose one of the first two readings, along with the third:

Lobell, D., W. Schlenker and J. Costa-Roberts, 2011. “Climate Trends and Global Crop Production Since 1980”, *Science*, 333(6042):616-620.

Schlenker, W. and M. Roberts, 2009. “Nonlinear temperature effects indicate severe damages to US crop yields under climate change”, *Proceedings of the National Academy of Sciences*, 106:37: 15594-15598.

Deryng, D., W.J. Sacks and N. Ramankutty, 2011. “Simulating the effects of climate and agricultural management practices on global crop yield”, *Global Biogeochemical Cycles*, 25, GB2006.

Textbook: Chapter 6: “Climate Change Impacts in Agriculture”

Lab Assignment 3: *Examine the impact of climate change on crop productivity, global land use and agricultural prices.*

Week 6: Supply response: Potential for Cropland expansion, Feb. 16 Lecture by Jing Liu, Post-doctoral Fellow, Department of Agricultural Economics

Absent sufficiently rapid yield growth, expansion at the extensive margin is inevitable. Many authors have asked the question: How much land is available for cropland expansion? And how productive is this land? If it is available, why is it not presently farmed? We will examine this issue. Ultimately cropland expansion will depend on the underlying economic forces – in particular the returns to land used in farming.

Required Readings:

Lambin, Eric. 2013. “Global Land Availability: Malthus vs. Ricardo”. *Global Food Security* (in press).

Villoria, N., D. Byerlee and J.R. Stevenson. (2014). “The Effects of Agricultural Technological Progress on Deforestation: What Do We Really Know?” *Applied Economic Perspectives and Policy*, doi: 10.1093/aepp/ppu005.

Textbook: Chapter 4: “Economic Response to Scarcity”

Lab Assignment 4*: Examine the combined impact of population growth, income growth and biofuels on global land use in the context of supply response at the intensive margin.*

Analytical Framework

Textbook Appendix B: “Analytical Framework: A Theoretical Model of Long Run Demand and Supply for Agricultural Land”

Week 7: Total Factor Productivity Growth in the Agricultural System, Feb. 23 - Lecture by Uris Baldos, Post-doctoral Fellow, Department of Agricultural Economics

Crop yield is a partial measure of productivity as it only reflects growth in output per unit of land input. To assess the overall changes in productivity in the agricultural sector, economists rely on total factor productivity (TFP) which takes into account all inputs used in production. During this week, we will explore the historical trends in agricultural TFP growth, its drivers, how changes in TFP affect consumers and producers and the implications of TFP growth on cropland use.

Required Readings:
Julian M. Alston, Jason M. Beddow, and Philip G. Pardey, “Agricultural Research, Productivity, and Food Prices in the Long Run,” *Science* 325, no. 5945 (September 4, 2009): 1209-1210.

Fuglie KO (2012) in *Productivity Growth In Agriculture: An International Perspective*, eds Fuglie, K.O., Wang, S.L. and Ball, V.E. (CAB International, Cambridge, MA, USA), pp 335–368.

Textbook: Chapter 3: Sections 3.3-3.4: “Productivity Growth and Yields in the Global Crops Sector”

Lab Assignment 5: *Examine the impact of changes in exogenous partial and total factor productivity growth rates in crops in different parts of the world on global land use.*

Week 8: Understanding the livestock sector and its role in translating changes in consumption patterns into land use, March 1: Guest Lecture by Farzad Taheripour, Research Associate Professor, Department of Agricultural Economics

The modern food system has reshaped consumption patterns around the globe. Growth in consumption and production of livestock products has been a key feature of this new economic geography of the food system. The most rapid increase in consumption of livestock products has been in developing countries. Much of this growth has been fueled by an intensification of livestock production. This sector has also become a major consumer of biofuel byproducts. This week we will examine how these factors combine to alter the demand for global cropland in the long run.

Required Readings:

Eshel, Gidon, A. Shepon, T. Makov and R. Milo (2014). "Land, irrigation water, greenhouse gas and reactive nitrogen burdens of meat, eggs and dairy production in the United States", *Proceedings of the National Academy of Sciences* 111(33):11996-12001.

Taheripour, F., C. Hurt and W.E. Tyner (2012). "Livestock Industry in Transition: Economic, Demographic and Biofuel Drivers", *Animal Frontier*.

Text: Chapter 9: "Livestock and Processed Foods"

Week 9: Food Waste and Post-Harvest Losses, March 8 – Guest Lecture by Jacob Ricker-Gilbert, Assistant Professor of Agricultural Economics

So far we have focused on the global dimensions of supply and demand. These are propagated throughout all the regions of the world, but their effects are modulated by regional differences in trade policies and the regulatory environment, including restrictions on water quality, use of GMO's, protection of native ecosystems, etc. In this week we will examine how these policies have been changing and what this means for global land use, and also how regulations will act to shape future land use.

Required Readings:

National Geographic. "One-third of food is lost or wasted: What can be done?", October 13, 2014; http://news.nationalgeographic.com/news/2014/10/141013-food-waste-national-security-environment-science-ngfood/

Z.B. Irfanoglu, U.L.C. Baldos, T.W. Hertel and D. van der Mensbrugghe (2014). "Mitigating global food losses and wastes by 2050: Implications for food and environmental security". Report prepared for the UN Food and Agriculture Organization.

Lab Discussion: *Impact of reducing food losses and waste on global food and environmental security.* ***Start working on class project***

SPRING BREAK

Week 10: Biodiversity and other Non-market, Land-based Eco-system Services, March 22, Jeff Holland, Associate Professor of Entomology

Thus far we have treated the ecosystem in a very simplistic fashion, with the main eco-system service provided by land being food production. However, there are many other services provided by terrestrial ecosystems – some of which benefit agricultural production and some of which have non-production values. In this week, we explore some of these other services – focusing especially on those which interact with agricultural production.

Required Readings:

L.A. Garibaldi et al., “Wild Pollinators Enhance Fruit Set of Crops Regardless of Honey Bee Abundance”, *Science*, 339, 1608(2013); DOI: 10.1126/science.1230200

T.H. Ricketts and E. Lonsdorf, (2013) “Mapping the Margin: Comparing Marginal Values of Tropical Forest Remnants for Pollination Services”, *Ecological Applications* 23(5):1113-1123.

Text: Chapter 7, Sections 7.1, 7.3, 7.4: “Land-based Environmental Services”

Lab Discussion: *Additional analysis of land supply shocks due to competing demands for ecosystem services.* ***Continue working on class project***

Week 11: Water Quantity and Quality: Constraints and Opportunities; March 29 Guest Lecture by Laura Bowling, Associate Professor, Department of Agronomy

Presently two-fifths of global crop production comes from irrigated areas which, combined, account for just one-fifth of total crop land. This is a reflection of the very high productivity of irrigated agriculture. However, this irrigation activity accounts for 70% of freshwater withdrawals, and projections indicate that 50% of global river basins will be experiencing severe shortages in twenty years’ time. This will inevitably translate into water scarcity and ultimately to reductions in the water available for farming. Thus water will be an increasingly key limiting factor for agricultural production in the coming decades.

Required Readings:

Jacob Burke and Karen Villholth, “Groundwater: a global assessment of scale and significance,” in *Water for Food, Water for Life*, ed. David Molden (London and Colombo: Earthscan and International Water Management Institute, 2007), 395-423;

Jelle Bruinsma, “The resource outlook to 2050. By how much do land, water use and crop yields need to increase by 2050?,” in *Session 2: The resource base to 2050: Will there be enough land, water and genetic potential to meet future food and biofuel demands?* (presented at the FAO Expert meeting on How to Feed the World in 2050, Rome, Italy, 2009);

Rosegrant, M.W., C. Ringler, T. Zhu, S. Tokguz and P. Bhandary. “Water and Food in the Bioeconomy: Challenges and Opportunities for Development.” *Agricultural Economics* (in press).
Text: Chapter 5: “Water, Food and Environmental Security”

Lab Discussion: *Analyzing the impacts of constraints in irrigated agricultural production to the global farm and food system* ***Continue working on class project***

Lab Discussion: *Examine the impact of changes in exogenous total factor productivity growth rates in livestock and food processing in different parts of the world on global land use.*
Continue working on class project

Week 12: Nutrition and Food Security: April 5 - Guest Lecture by Bruce Hamaker, Distinguished Professor of Food Science and Director, Whistler Center for Carbohydrate Research

Nutrition and food security are closely linked to developments in the agricultural sector particularly in low income regions. Given this, the impacts of climate change on agriculture will affect the nutritional outcomes at the household level. In this week, we examine the key measures used in quantifying hunger and malnutrition and how these metrics are affected by climate change and by the long run drivers of the global food and farm system.

Required Readings:

Black, R.E., L.H. Allen, Z.A. Bhutta, L.E. Caulfield, M. de Onis, M. Ezzati, C. Mathers and J. Rivera. (2008). “Maternal and Child Under-nutrition: Global and Regional Exposure and Health Consequences”, *Lancet* (371):243-260.

United Nations Standing Committee on Nutrition (2004). Chapter 2 of the *Fifth Report on the World Nutrition Situation: Nutrition for Improved Development Outcomes.* Geneva: United Nations.

Textbook: Chapter 10: “Food Security and Nutrition”

Lab Assignment 6: *Examine the nutritional implications of climate change and the drivers of global agriculture.*

Economic Modeling Framework

Baldos, U. and T. Hertel (2014). “Global Food Security in the Long Run: Implications of Agricultural Technology”, *Australian Journal of Agricultural and Resource Economics*.

Week 13: Land-Based Climate Mitigation Policies, April 12 - Lecture by Tom Hertel

Most land management policies aimed at curbing GHG emissions and mitigating the effects of climate change are directed toward restoring and preserving natural forests. However, these policies will have unintended consequences on the availability of farmlands in the future. Some studies also point out the potential for GHG mitigation in the agricultural sector by reverting current croplands to its natural land cover. During this week, we will explore the effect of these land-based climate mitigation policies on global crop production and food prices.

Brent Sohngen, “An Analysis of Forestry Carbon Sequestration as a Response to Climate Change” (*Copenhagen Consensus on Climate*, 2010)

Golub, A.A., B.B. Henderson, T.W Hertel, P. Gerber, S.K. Rose and B. Sohngen (2012). "Global Climate Policy Impacts on Livestock, Land Use, Livelihoods and Food Security", *Proceedings of the National Academy of Sciences*.

Text: Chapter 7, Sections 7.2, 7.5: "Land-based Environmental Services"

Lab Discussion: *Examine the impact of land use change on GHG emissions. Explore exogenous shifts in the supply of land to agriculture in response to climate mitigation policies.*
Continue working on class project

Week 14: Globalization, and the scope for feeding the world sustainably in 2050, April 19 – Lecture by Uris Baldos

This course has surveyed the major drivers of land supply and demand and how they are studied. In this week we will attempt to synthesize the strengths and weaknesses of different research approaches and identify promising new directions for better understanding the future global food, land and environmental systems.

Required Readings:
Eric Lambin and Partick Meyfroidt, "Global land use change, economic globalization and the looming land scarcity", *Proceedings of the National Academy of Sciences,* www.pnas.org/cgi/doi/10.1073/pnas.1100480108

Pete Smith et al., "Competition for Land", *Phil. Trans. R. Soc. B* 2010 (365): 2941-2957, doi: 10.1098/rstb.2010.0127

Text: Chapter 11: "Global Change and the Food System in 2050"

Lab Discussion: *Incorporate projected growth in the key drivers of global agriculture and discuss the range of future growth in crop production, cropland use and crop price.*
Finalize class project

Week 15: Presentation of Class Projects, April 26 and 28

Each individual will briefly present highlights from their class project, with time for Q&A with the rest of the class. A menu of project ideas from previous years follows. This is indicative of the type of question which can be readily explored in the context of the SIMPLE modeling framework developed over the course of the semester.

Ideas for Class Projects

(We expect that many more ideas will emerge from our discussions during class):

1. ***Food Waste and Post-Harvest Losses:*** The UN-FAO estimates that one-third of global food production is lost or wasted so that only two-thirds of production is actually consumed. What are the implications of such losses for crop prices? How would a reduction in post-harvest losses affect nutritional outcomes?
2. ***Changing Nutrition Guidelines:*** The USDA is in the process of formulating a new set of nutrition guidelines. For the first time they are considering adding environmental impacts to these guidelines. How would such considerations change the pattern of food consumption? How would changing consumption patterns alter the pattern of global land use and GHG emissions?
3. ***Empowerment of Women: Implications for Global Food Security:*** Women comprise a large share of the agricultural labor force and female-headed farms represent a large share of agricultural enterprises worldwide. Women are also key decision makers when it comes to household nutrition and fertility. As such, they are in a unique position to influence local, regional and global food security outcomes. However, lack of education and limited access to credit and other inputs currently limit the impact which women can have on these outcomes. How would greater empowerment of women change the global food security landscape?
4. ***Migration and Global Food Security:*** The migration of individuals across national borders is a global phenomenon which is currently on the rise. It affects for the supply of, and the demand for, food. What is the net impact on global food security of trends in international migration?
5. ***Virtual Trade in Water:*** Scientists have recently identified 'virtual trade in water' as an important element of the global sustainability puzzle. Virtual water exports arise when one country exports water intensive goods to another country. The water embodied in the production of this commodity for export is termed 'virtual water' and recent studies have documented the extent of such 'trade'. In light of the trends in population, income, productivity and biofuels alter virtual water trade between the present day and 2050?
   Constraints in irrigated agriculture: Almost 40% of the world crop production is coming from irrigated lands. However, growing scarcity of water threatens to limit the potential of irrigated agricultural production to feed the world. Excessive water withdrawals also threaten to increase soil salinity and soil productivity. What are the potential impacts of constraints in irrigated agriculture on the global farm and food system.
6. ***Africa as the Sleeping Giant of Agriculture:*** In 2009, the World Bank published a report suggesting that the Guinea Savannah Zone of Africa could become the next breadbasket for the world. What would be the implications of such a development?
7. ***Urbanization:*** In one of our lab discussions, we explored urbanization's impacts on demand for land. However, one could dig deeper by looking at the quality of land that is being displaced. What are the implications for global land use, food security and the environment.
8. ***REDD:*** Similar to **Urbanization**, students could explore the impact of efforts to dedicate additional land to the production of environmental services. This would be implemented through adjustments to the regional conversion factors of land in environmental services to cropland.
9. ***Climate change:*** We also explored in our lab discussions the impacts of different types of climate shocks on agricultural productivity and land use. A deeper dive might entail converting existing studies of the impacts of climate change into shocks or parameter

adjustments within our own model and exploring the results. Lab four discusses the parameters that could be adjusted to implement this idea.

10. ***Jevon's paradox:*** The Angelsen reading discusses Jevon's paradox - a situation in which yield growth might lead to extensification. A deeper exploration of the conditions under which we might expect such a result would be interesting. What is the demand elasticity required to generate this outcome? How do yield differentials across regions affect the likelihood of this outcome? Can these results tell us anything about the probability of experiencing Jevon's paradox in the real world?
11. ***Impacts of shifting population and income on global demand elasticity:*** Regional differences in demographics and income growth will shift the balance of global demand. How do these shifts change the aggregate global demand elasticity? How does this compare to shifting demand elasticities within regions? What impact does this have in moderating/amplifying the extensification impacts of biofuels mandates?
12. ***Biophysical/economic interaction:*** Relative yields (local yields versus the global maximum) might be indicative of how close a particular region is to the biophysical limits of intensification given current technologies. To understand how such biophysical limits interact with the economics governing the crop market, we might want to consider a linear relationship between relative yields and our intensification parameter. By plotting different regions on this linear relationship, one could determine whether such a biophysical limit, through its impact on the economic parameters, changes the outcomes of crop expansion scenarios.
13. ***Impacts of different types of technology growth:*** In our model we can simulate land augmenting, land dis-augmenting and technology neutral productivity growth (through afland, afnland or both simultaneously). What are the realistic ranges of these types of productivity growth going forward? If yield growth outpaces non-land technology growth, what would be the impact on prices and extensification? Under different scenarios, does the clear relationship between land prices and extensification begin to break down?
14. ***Globalization:*** We have spent relatively little time in the labs relating global processes to local outcomes. However, it can be shown analytically that the *effective* elasticity of demand for a local market depends on the rest of the world's supply elasticity, the local production's share of the global market as well as the global demand elasticity. Among other possibilities, an analysis of globalization's impact might compare the extensification impacts of productivity changes in small markets (share of world supply is small) to large markets.
15. ***Changing productivity of livestock and food processing:*** We've spent a fair amount of time evaluating the impacts of changing agricultural productivity. However, one could also assess the implications of changes in the TFP of livestock production or food processing. Contradictory effects of these downstream productivity changes (less crops required to produce a good, but demand is now increasing) may lead to interesting results depending on the assumed parameter values.
16. ***Market mediated responses:*** Hertel (2011) highlights the importance of considering economic factors when estimating the land use implications of changes in biofuels demand. A similar analysis could assess to what scale biophysical estimates of the impacts of demand shocks (e.g. population growth, income expansion) are moderated through economic processes such as intensification and demand reduction.
17. ***Cost-benefit analysis of productivity growth:*** Several papers provide estimates of the cost and scale of historical TFP growth. Using these estimates, one could estimate the consumer surplus generated by the yield growth to evaluate the cost effectiveness. Similarly, estimates of the cost per hectare saved would be possible for land-sparing technologies.