Teaching and Educational Methods

Educating the Next Generation of Interdisciplinary Researchers to Tackle Global Sustainability Challenges: A Graduate Course

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Abstract
This paper describes an innovative graduate course in agricultural economics that has evolved over the past decade and attracts students from across the Purdue University campus. Its novel combination of guest lectures on key sustainability topics, and intensive, computer-based lab assignments with the SIMPLE model of global food and environmental security, prepares students to undertake innovative projects. These independent projects are presented to the class, written up, and submitted in lieu of a final exam. The topics covered are quite diverse and range from the impacts of women empowerment on food security, to the consequences of heat stress on farm workers, and the impact of reducing food waste. The course has spawned two dozen published journal articles, inspired MS and PhD theses, and facilitated a number of important interdisciplinary projects. The complete syllabus, lab assignments, and detailed course design are made available for others to use and adapt to their own circumstances. Future versions of the course will seek to incorporate explicitly spatial analysis of agriculture, land, water, and environmental quality outcomes.

1 Introduction

Effective functioning of the global food system is critical to human well-being on the planet—providing nutrition, employment, other ecosystem services, as well as an important source of income for hundreds of millions of people, including a majority of the world's poorest households. However, this same food system is transforming our natural environment. These stresses have recently been conceptualized as risks to the "safe operating space" within the earth's planetary boundaries (Steffen et al. 2015). Exceedances of these planetary boundaries represent potentially irreversible alterations of the earth system. Conversion of natural lands to farming and loss of biodiversity, pollution from excess nutrient applications in agriculture, the depletion of groundwater stocks, and the emission of climate-altering greenhouse gases all pose significant risks to the planet (Hertel 2011). Balancing the critical role of the food system in feeding the world's growing population while respecting these planetary boundaries is one of the grand challenges faced by society today, and solving this challenge requires collaboration across many diverse disciplinary boundaries (Springmann et al. 2018).

This article describes a graduate course offered at Purdue University that teaches students how to analyze and find solutions for this suite of sustainability challenges within an economic framework, but drawing on a wide range of disciplines. The course is based in the Department of Agricultural Economics and is titled: "AGEC 528: Global Change and the Challenges of Sustainably Feeding a Growing Planet." It allows students to explore the trade-offs and synergies arising out of the competing demands on the planet's finite land and water resources, for which agriculture is the dominant user (Molden et al. 2007; Ramankutty et al. 2008). Identifying potential pathways for sustainable development in the coming decades will inevitably require transformation of the world's food systems (FAO 2018). Analysis of these trade-offs and potential transformational changes is undertaken within the context of an economic modeling framework nicknamed SIMPLE: a Simplified International Model of Prices Land use and the Environment (Hertel and Baldos 2016). This framework keeps the economics as simple as possible in order to allow the model to be widely accessible to non-economists. SIMPLE has proven amenable to integrating insights and knowledge from a variety of different disciplines, including agronomy, climate science, ecology, hydrology, engineering, nutrition, as well as a variety of social sciences (Hertel, Ramankutty, and Baldos 2014; Liu et al. 2017; Lopez Barrera and Hertel 2020; Lobell, Baldos, and Hertel 2013; Baldos and Hertel 2014).

Students learn about the global drivers underlying the evolution of the food system and associated sustainability challenges—focusing specifically on land, water, and natural ecosystem services. Students also explore how infringement on the planetary boundaries, as evidenced through water scarcity or climate change, for example, may alter the functioning of the food system.

2 Course Design

This is a 3-credit class, meeting twice a week for a full semester (15 weeks). The first meeting of each week introduces a new dimension of the food system and its interaction with the natural environment (Table 1). We initiate the week's activities with two contemporary readings on the topic, as well as a chapter in the textbook (Hertel and Baldos 2016). Articles are typically drawn from recent issues of top interdisciplinary journals such as *Nature*, *Science*, *Proceedings of the National Academy of Sciences*, and *Global Environmental Change*. Students are required to post two questions based on each of the readings in a shared directory (we use Dropbox). This provides an added incentive for timely submissions, as everyone, including the instructor, can see who has offered questions for the week. The submissions are compiled and structured into a coherent set of topics/themes by one of the students who then leads the discussion following the guest speaker's presentation.

Guest lectures are provided by domain experts drawn from relevant fields, including: agronomy, climate science, demography, ecology, economics, engineering, geography, hydrology, nutrition, and political science. They speak for 45 minutes (time limit is strictly enforced), leaving 30 minutes for student-led discussion. This format has proven to provide a good balance between delivery of new content and student engagement. Speakers are provided with the curated list of questions in advance. Students come from the Colleges of Agriculture, Engineering, Liberal Arts, Management, Science, and Technology, so the questions are wide-ranging and typically engage the speaker in a variety of (often unexpected) ways. As a result, the speakers have found this to be a rewarding experience, and, to date, they have always accepted return invitations!

Table 1. Topics Covered in the Course

- Planetary Boundaries and the Food System
- Population Growth and Global Food Demand
- Yield Growth and Yield Gaps
- Total Factor Productivity Growth
- Potential for Cropland Expansion
- Water Availability: Constraints and Opportunities
- Globalization
- Consumer Preferences for Food
- Nutrition and Food Security
- Post-Harvest Losses
- Linking Biodiversity and Agricultural Production
- Environmental Impacts of Agriculture: Water Quality
- Environmental Impacts of Agriculture: Greenhouse Gas Emissions
- Climate Change as a Factor Influencing Global Agriculture

Table 2. Lab Assignments in the Course

Assignment 1: Simulate the impact on global and regional food demands in 2050 of varying assumptions about population growth and the income responsiveness of food demand.
Assignment 2: Analyze the impact of population growth projections on world food markets under varying assumptions about the price responsiveness of the extensive and intensive margins of supply, as well as consumer demand.
Assignment 3: Examine the impact of economic growth and climate change on crop productivity, global land use, agricultural prices, and undernourishment globally and by major world region.
Assignment 4: Examine the consequences of international economic integration for the effectiveness of sustainability policies.
Assignment 5: Gridded analysis: Explore the consequences of changing irrigation efficiency for aggregate water withdrawals across a range of grid cells in the continental United States.

The second meeting of each week is "lab day." Using graphical exercises, mathematics, computer simulation, and numerical analysis, we explore the economic dimensions of the weekly theme and how it relates to the global food system, resource use, environmental quality, and nutritional outcomes. The core economic concepts are developed in the context of five lab assignments (Table 2). These lab assignments are based on the SIMPLE model (Figure 1) and are designed to allow students to obtain a hands-on assessment of the relative importance of the forces bearing on the long run supply and demand for food and natural resources, key economic mechanisms mediating these adjustments, and the implications for food security and the environment. Labs are implemented in the GEMPACK software (Harrison and Pearson 1996), which was developed explicitly for solving and analyzing economic equilibrium models. Because the model is expressed in linearized form (i.e., in terms of elasticities, cost, and quantity shares, etc.), it is straightforward to analyze. Analysis is greatly facilitated via the extremely useful

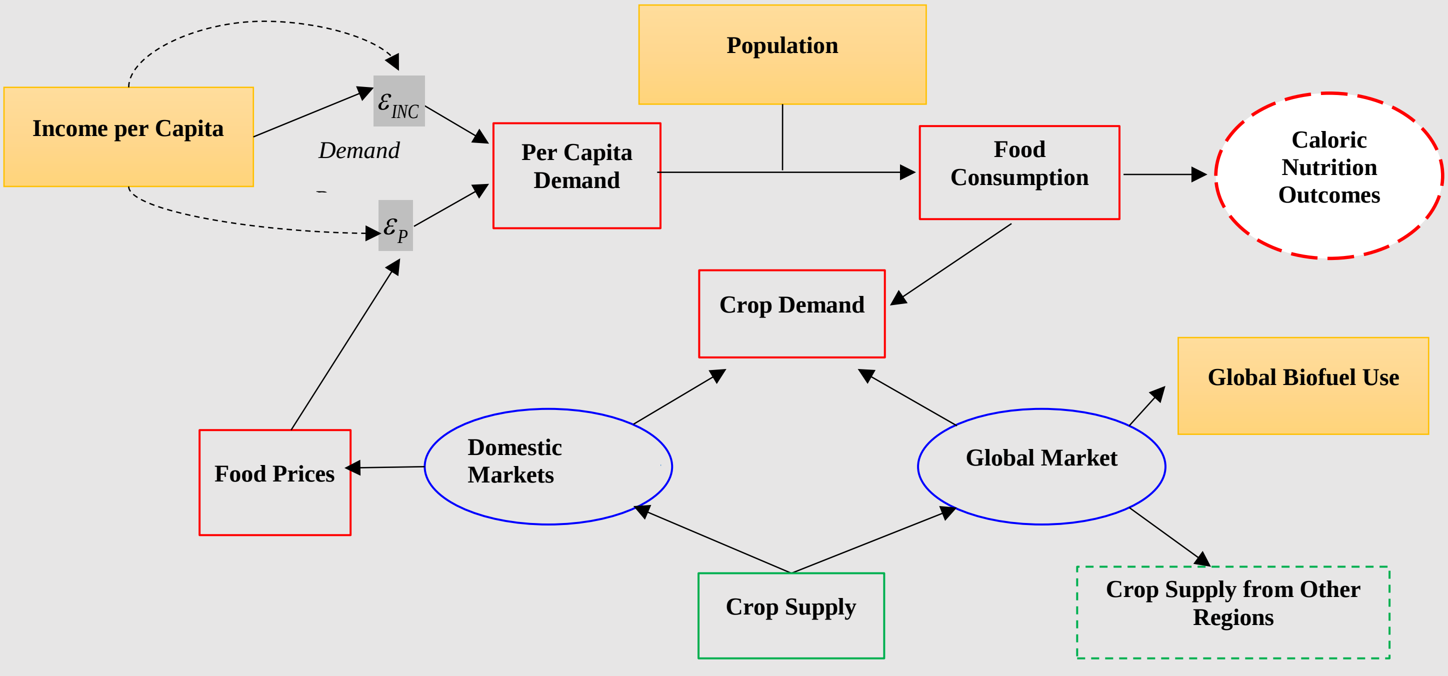

Figure 1. Overview of the SIMPLE Model

AnalyseGE interface that assembles in one place the: model equations, model solution, initial data (and shares), and also the parameters. A series of mouse clicks allows the user, for example, to decompose the intensive and extensive margins of supply response and analyze why this might differ across regions. Furthermore, since the underlying nonlinear model is solved in such a way as to allow the shares and elasticities to vary over the course of the simulation (e.g., the income elasticity of demand for food products declines as households become richer), students can undertake large change experiments, such as projecting the global food economy to 2050.

The labs begin by focusing on key demand drivers: population and income, bringing in the supply side in the second lab assignment. Global food supply is governed by three factors: the extensive margin of supply (cropland expansion), the intensive margin of supply (increasing the intensity of nonland input usage), and total factor productivity growth (introduction and adoption of new technologies). A caloric nutritional attainment module is introduced in the third lab assignment, along with climate change scenarios. The fourth lab focuses on the theme of globalization and explores how global market integration alters sustainability outcomes. The fifth, and final, lab uses the gridded version of SIMPLE to explore issues related to irrigation and groundwater sustainability in a spatially explicit manner.

The capstone event in this course is the student project, which involves the application of SIMPLE to a problem of the student's choosing (Box 1 provides some recent examples). Most students come into the course with some specific ideas about sustainability and potential solutions to the environmental and food security issues facing the world today. We begin discussing their ideas in the first week and continue these informal discussions throughout the first half of the semester. As they undertake the lab assignments, these ideas typically evolve and become more refined. After spring break (halfway through the semester), I meet with the students individually—or in some cases in pairs—to finalize their project concept (There are typically about sixteen students in the class.)

Box 1. Topics Addressed in Previous Course Projects

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 greenhouse gas emissions?
3. *Regulating Nonpoint Source Pollution from Agriculture:* Arguably the most important environmental problem surrounding agricultural production in the midwestern United States is the run-off of excess nutrients into streams, rivers, and coastal ecosystems. The resulting incidence of hypoxic "dead zones" has led to calls to greatly restrict nutrient use in agriculture as well as investing in conservation policies. How will such regulations affect production, prices, and food security? Which are the most effective policies?
4. *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 that women can have on these outcomes. How would greater empowerment of women change the global food security landscape?
5. *Migration and Global Food Security:* The migration of individuals across national borders is a global phenomenon that 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?

Box 1 Continued

6. *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, will the pattern of virtual water trade be altered between the present day and 2050?
7. *Constraints on Irrigated Agriculture:* Almost 40 percent 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?
8. *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?
9. *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?
10. *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.
11. *Climate Change:* We also explore 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. It is also possible to consider the impact of elevated heat and humidity on labor capacity in agriculture and the consequences for food prices.
12. *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?
13. *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?
14. *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.
15. *Impacts of Different Types of Technology Growth:* In our model, we can simulate land augmenting, land disaugmenting, 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 nonland 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?

Box 1 Continued

16. *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.
17. *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 total factor productivity 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.
18. *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.
19. *Economic Impacts of Biodiversity Loss:* Cropland expansion and intensification have been shown to result in biodiversity loss. One source of biodiversity that is important for agriculture is the presence of natural pollinators. What are the impacts of pollinator loss on agricultural yields, and hence the need for further cropland expansion?
20. *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.
21. *Water Quality Trading in the Chesapeake Basin:* We have examined the impact of fertilizer use in agriculture, as well as the consequences of excess nutrients for water quality. This is a particularly important problem in the Chesapeake Bay region. Using the gridded version of SIMPLE-G, it is possible to develop nitrate leaching mitigation cost curves to explore the potential for profitable pollution trading with industrial and municipal point-sources of pollutants.

Throughout the second half of the semester, students submit weekly updates on their projects, starting with an outline and then progressing from experimental design to results and analysis. Students typically use one of the lab assignments as a starting point for their project and introduce changes to production technology, consumer preferences, or public policies for subsequent analysis. By keeping tabs on the students each week, it allows me to head off unproductive and possibly erroneous lines of work while also keeping the students motivated (see Supplementary Table S1 for the project rubric and schedule). In the final week of classes, students make a short presentation focusing on the problem motivation, experimental design, and a few key findings. Their final task is to write this up in a short paper (10 pp. maximum text, unlimited figures, and tables permitted), which is submitted in lieu of a final exam. Grading is based on class participation, lab assignments, and the final project.

3 Evolution of the Course

When this course was first initiated in 2011, the world was in the midst of a food price crisis (Abbott, Hurt, and Tyner 2011). I had recently given an AAEA Presidential Address on a related topic: "The Global Supply and Demand for Land in 2050: A Perfect Storm in the Making?" (Hertel 2011), and was headed for a sabbatical with the Center for Food Security and the Environment at Stanford University where I co-taught, together with my host, David Lobell, an interdisciplinary seminar in the Department of Earth Systems Science. This course was advertised across campus and open to all graduate students as well as advanced undergraduates. We ended up structuring the course around the AAEA Presidential Address, with each week tackling a different theme. This was my first introduction to teaching an interdisciplinary course, and we utilized a number of key elements that I still employ—nearly a decade later. The first is the idea of inviting a different domain specialist to speak each week. The second is to follow the lecture with student-led discussion, with one individual in charge of leading this discussion each week. The idea of class projects was a natural outgrowth of this format and had proven success in prior classes.

The SIMPLE model was born during this period. Based on my previous experience with the Global Trade Analysis Project (GTAP; Hertel 1997), I recognized the power of having a standardized computational framework for teaching applied economics. The GTAP model was released in 1993 in conjunction with the annual short course in Global Trade Analysis and that course has subsequently been offered on a continuous basis for nearly three decades. The content cross-fertilized with a PhD course in applied general equilibrium analysis. Following this example, for the new interdisciplinary course, my collaborator Uris Baldos and I developed a global, partial equilibrium model that was a disaggregated, numerical expression of the theoretical model introduced in the presidential address. Based on my positive experience with the GEMPACK software package (Harrison and Pearson 1996) for teaching the GTAP courses, we adopted that software suite for SIMPLE as well. Our strategy was to keep the model as simple as possible—eliminating "nice to have" flourishes in favor of a stripped-down analogue to the theoretical model—since the latter could be solved analytically and therefore was a useful source of insight and intuition into the model simulations. This allowed the students to quickly grasp the key economic mechanisms at work and begin to exercise them in the context of their own projects.

Influenced by the climate scientists around me at Stanford, the first major exercise we undertook with SIMPLE was to run it backward over time. Given our interest in projecting forward 45 years (2006–2050), we decided to backcast from 2006 to 1961, which also happened to be the starting point for the FAO data series upon which we relied for much of our data. This resulted in a novel paper critiquing the literature on global land use change projections (Baldos and Hertel 2013). In particular, we found that the tendency of the prominent Integrated Assessment Models at the time to predict massive land conversion for agriculture in the 21st century was a direct consequence of their failure to incorporate key economic margins of response—most notably the potential for endogenous intensification of production in response to rising land prices. By using the 1961–2006 historical period as our laboratory, we were able to show how such an assumption resulted in far more land conversion than had been historically observed. This was our first indication that SIMPLE could be an effective vehicle for advancing interdisciplinary research. Indeed, after witnessing the development of increasingly complex models, journal reviewers at the time welcomed the use of a model that they could actually understand!

From an initial focus on food and resource scarcity, the course has evolved to focus on the agriculture-environment interface and planetary boundaries. This evolution has mimicked the changing interests and publications in the top interdisciplinary journals such as *Science* and *Nature* (Steffen et al. 2015; Springmann et al. 2018). Each year, the syllabus is updated, and periodically some topics are dropped (e.g., biofuels) in favor of emerging topics (e.g., biodiversity; consumer-driven sustainability). In this way, the course has remained relevant to students across campus.

4 Course Impacts

The course has been well-received by students with recent overall course ratings (as opposed to instructor ratings) of 5.0, 4.5, and 5.0 where 5 denotes excellent. In preparation for writing this article, I sent out a request to recent graduates of the course, asking them to describe how the course influenced them—in particular their outlook on economics (for the non-economists) and interdisciplinary work. Excerpts from these responses are provided in Box 2, along with the major field of study of the graduate student responding. From these comments, it is clear that, for scientists with an aversion to economics, this can be a good entry point to learning the value of economic thinking. And for the economists, the most important feature of the course seems to be the opportunity to think about the "big picture," as well as the exposure to new research ideas.

Box 2. Impacts on Students (Major Field of Study in Parentheses)

Comments from Non-Economists

"I thoroughly enjoyed AGEC 528 this semester. I learned a great deal about Agricultural Economics, and the strong link it has to my field of study (applied climatology). I enjoyed that the course was open to all majors, as it provided insightful discussion and different viewpoints on reading assignments for the course. I like the inclusion of lab assignments with SIMPLE, as it helped me breakdown economics in a manner I am familiar with (modeling of complex systems) leading to a deeper understanding of the intricate nature of the agricultural-economic system. I have struggled with economics in the past, but after taking the course, I have developed a much greater appreciation and deeper understanding of the science, especially since I was able to make economics applicable to my own field of study." **(Climate Science)**

"Because Ag Econ was outside of my discipline, I found this class very helpful. I learned a lot about economic modeling, it's strengths and weaknesses, how the models are made, what kinds of assumptions go into them, and how to interpret the results. Of course, I was not an expert upon finishing the class, but the introduction was very valuable. In addition, seeing the interconnectedness of different variables in the unique study of Global Land Use was very helpful in following the news." **(Agricultural Engineering)**

"I really enjoyed this class. I felt like I was able to grow in a direction I would have not otherwise been able to explore. I had joined the Ecological Sciences and Engineering program to explore interdisciplinary work, but I still had a barrier setup, and it felt like economics was on the other side of that barrier. After taking the class, I would say that changed. I initially felt very comfortable with the lecture and discussion portion of the class, as I thrive learning in that format. However, I felt uncomfortable with the labs (once again the barrier). However, I became invested in my project, and that is what really changed my perception about my ability to incorporate economics into future research or at least to identify the need to do so. My career goal is still to eventually work on interdisciplinary teams focused on wicked environmental problems, so I think that this class really benefited me." **(Agricultural and Biological Engineering)**

"I am not an economics person. I believed more in production to solve the world's food problem. Taking this class changed that view. It exposed me to the deprivations I would suffer from if I do not pay attention to economic activities that directly impact my immediate environment as well as the world view too. I got exposed to many challenges that exist in agricultural productivity and the multidisciplinary approach to solving them. I got more interested in world trade and learned to foresee the implications of my activities and decisions on the poor and rich at the national, continental, and world level." **(Agronomy)**

"Prior to the course, I had a very limited view of agricultural and applied economics. Now that I understand that there's a lot of good work being done in the area, and now that I have a better appreciation for what's possible with state-of-the-art economic modeling tools. I expect to apply insights from economic modeling or even leverage models from the economics literature as I continue to pursue a research career in natural hazards mitigation. I'm currently working on expanding my final project into something publishable and policy-relevant with the assistance of my advisor as well as Professor Baldos. Additionally, the course provided an excellent networking opportunity; I connected with several interesting and capable fellow researchers who I now consider friends." **(Industrial Engineering)**

Box 2 Continued

"In my case, AGEC 528 made me realize how the agricultural challenges that we face impact in the world economy and the people. The kind of analyses that we did in the class made me think how we can model and replicate different situations in order to develop better policies for the common welfare. My masters program is in Horticulture combined with Agricultural Economics, and this class made me eager to look for a PhD in Agricultural Economics." **(Horticulture)**

"AGEC528 class changed my perspective and helped me answer important aspects of post-harvest losses which I later adopted in my thesis. Coming from a non-economics background, I had very little idea about how can one apply economics to study the impact of environmental factors in agriculture. I believe that AGEC528 (irrespective of academic background) provides everyone with an opportunity to see the world of agriculture from an entirely different economic lenses and focus more toward our contribution toward sustainability and food security for our future needs." **(Engineering Technology)**

"I really enjoyed the AGEC 528 class and learned a lot about agricultural economics concepts and how they relate to solving the problems in agriculture production sustainably. I have an Industrial Engineering background. However, I found it quite easy to learn and understand the concepts. I think the simulation software (SIMPLE) that we used in the class helped to apply the concepts and analyze the problem in greater depths. The final team project that we did helped me to understand the relationship between economic factors (TFP, labor productivity) in agricultural production with environmental factors (heat stress, malnutrition) in different regions of the world." **(Industrial Engineering)**

"The FAO estimates over 2 billion people do not have regular access to safe, nutritious, and sufficient food. There are very few issues that our generation face more important than this one. AGEC 528, in conjunction with my program in Ecological Sciences and Engineering, has broadened my horizons to the positive impact that interdisciplinary work has, especially in the world of food security. I really enjoyed learning and reading about a different topic each week. The issue of food security is so complex, and it seems this is the only true way to teach the subject. I really appreciated how applicable the readings of this class were to current events. As a non-economist, the course opened my eyes to the world of ag-econ and its quintessential importance for global food security. I am not a naturally strong student in the area of coding and computing, but this course taught me in a way that I could understand and create a final project based on a computer modeling system. I never thought I would say that!" **(Ecological Sciences and Engineering)**

Comments from Students in Agricultural and Applied Economics

"The best and simplest way I can describe my experience from this class is that it allowed me to think 'bigger picture.' As students of economics, we can often get consumed in microenvironments/micro-interactions that sometimes we forget that any small change in an economy can have ripple effects on many different sectors, within supply chains, and trade between nations. This class allowed me to think through many of these potential impacts, even before running any simulations. Better yet, once simulations had been run, I could reason through why the results may have come out the way they did because of these simple thinking exercises. The interdisciplinary nature of the course reinforced my views that the study of human action and interaction with the natural world is the sum of many different disciplines. Using the combined tools of the natural sciences and social sciences help us form a better understanding of the 'bigger picture.'" **(Agricultural Economics)**

Box 2 Continued

“AGEC 528 has been an eye-opener to me in many ways. I joined Purdue in 2019 aspiring to become an applied microeconomist and always dreaded complicated macro theories or anything to do with macroeconomics in general, until I took this course in Spring 2020. I have never been in a class before where a complex modelling technique was introduced with so much simplicity and made even more interesting by complementing the technical lab sessions with interdisciplinary guest lectures and making us apply the model to pressing real-world issues. It was also a great networking experience, interacting with peers researching in other interdisciplinary areas.” **(Agricultural Economics)**

“This class allowed me to find my passion within the field of applied economics and agricultural economics, and it made a huge impact on my academic trajectory. In this class, I became fascinated with the tradeoffs and synergies arising out of the competing demands on the planet’s finite resources, as well as potential pathways for sustainable development in the coming decades. The topics, the dynamics of the course, and the methodology applied really triggered my interests. But most importantly, it widened my perspective on how economics could contribute to other disciplines. I have been developing a big portion of my PhD dissertation around extensions of the nutritional module in SIMPLE. Since Spring 2019, I have been serving as TA for this course, and I have seen the same effect on many other students. Looking back, the impact of this course on my career has been tremendous. After finishing my PhD, I plan to stay in academia hoping that my research helps achieve a sustainable future as well as helping to educate students with an interest in these topics. And all of that was inspired by the AGECON 528 course.” **(Agricultural Economics)**

“AGEC 528 in essence changed my career from financial management to agricultural economics. I was impressed by the multidisciplinary design of the course. Frankly, it was my first experience with multidisciplinary course. Sitting in this class was a great chance to look at the big picture of a critical challenge, which is feeding the world in 2050. Speakers from different disciplines were sharing their views and articles relating to this issue. It was really informative how tradeoffs appear between different disciplines like economics and environment.” **(Agricultural Economics)**

“As a graduate student, it’s very easy to get absorbed in the importance of our own (usually narrowly focused) research projects and forget that it doesn’t exist in isolation. While every research problem is still important, other problems also exist and are often related and embedded within more complex “wicked problems” like food security. AGEC 528 was a good reminder of this and helped me put my own research topic (storage loss) in perspective. I think that it’s important and humbling for any grad student to see how their research fits into the bigger picture, and that research can be much more impactful by thinking beyond just one narrow question or issue. Even as an economist, I appreciated the simplicity of the economics discussed in the course. It allowed me to focus more on the modeling, and how the interdisciplinary topics are applied and measured in the model. The modeling helped me understand these topics from a more macro perspective, rather than at the micro-level approach I use in my own research.” **(Agricultural Economics)**

One of the biggest benefits of teaching this course has been the impact it has had in shaping my research, greatly enhancing my interdisciplinary collaborations. This course has directly, or indirectly, spawned two dozen journal articles as well as a textbook. Most of these have been born out of discussions—sometimes heated debates—with students and guest speakers on topics such as Jevons' paradox (Hertel, Ramankutty, and Baldos 2014). Others have emerged from an attempt by the visiting lecturer and myself to forge a synthesis between our respective fields—for instance economics and ecology (Seppelt et al. 2020). By inviting a rotating group of scientists to speak in the course, I have also been able to forge productive interdisciplinary collaborations. If not well-matched, such collaborations can prove frustrating and costly—both in time and resources. The trick to successful interdisciplinary collaboration is to identify like-minded individuals whom one enjoys engaging in discussion and inquiry. By sharing the syllabus with guest speakers in advance, settling on a couple of recent readings, listening to the guest lecture, and observing how these individuals interact with the students, I have found it is possible to form a reasonably accurate assessment of the likelihood for a successful collaboration emerging.

The core group of lecturers whom I identified at Purdue University in the first few years of the course also became the foundation for two successful campus-wide interdisciplinary competitions. The first was sponsored by the Mellon Foundation and emphasized the communication of interdisciplinary research around the "grand challenges" facing the world today. Our project focused on the long run sustainability of U.S. agriculture and culminated in an event at the National Press Club in September 2018.[1] The second was a research competition attracting submissions from nearly 50 competing interdisciplinary groups across campus, focusing on Big Ideas—in this case related to sustainability.[2] We would not have been successful in these competitions (typically announced with just a few months' lead time) if we had not identified like-minded collaborators in advance and begun fleshing out the themes for these projects in the context of our interactions through this graduate course. One of the most satisfying impacts of the course has been to see student projects evolve into thesis topics, and later into journal articles. More often than not, these students have introduced me to new areas of inquiry, thereby broadening my horizons and lending an interesting dynamic by which the course content evolves over time. Two notable examples of such student-led initiatives are: the role of food waste in global food security and environmental sustainability (Lopez Barrera and Hertel 2020), and the impact of heat stress on agricultural labor capacity (Lima et al. 2020; Hertel and de Lima 2020).

5 Challenges and Future Opportunities

The foremost challenge facing those offering such a course is to keep it fresh and exciting! As this is an elective course, demand can quickly dry up if students no longer find this to be sufficiently innovative. Also, there is continuing competition for "global food security" types of courses offered elsewhere in the university. The differentiating factor in this course is that it is model-based, and students learn how to use this model through a systematic series of labs. This is what gives them the capacity to ultimately bring the SIMPLE model to bear on an issue of particular interest to them. It is this last step which the students find most meaningful. This is quite different from a readings-based course—which typically culminates in a readings-based term paper. Such courses are valuable, but often leave students wondering how they can apply this newfound knowledge to address the world's food and environmental security challenges.

A second challenge is the labor-intensive nature of the course. We are teaching economics at the same time we are teaching students how to generate and analyze results from a global economic model, in addition to introducing specialized material on a wide range of sustainability topics. In the first few years, the course was co-taught with Uris Baldos, my co-author and collaborator in development of the

[1] https://mygeohub.org/groups/glass/npc2018
[2] https://www.purdue.edu/discoverypark/initiatives/big-idea-challenge/

SIMPLE model. This collaboration launched the course and also gave rise to the textbook which we co-authored. For each chapter/sustainability topic, Uris developed a computational example using the SIMPLE model. After Professor Baldos moved on to a new position, I recruited a PhD student from our department who had excelled in the previous year's course. Iman Haqiqi assisted with the labs and projects for several years, gaining valuable teaching experience and contributing to new pedagogical material for the lab assignments and associated tutorials. Dr. Haqiqi has subsequently used the SIMPLE model in his own research (Haqiqi et al. 2018; Baldos et al. 2020). The most recent PhD teaching assistant for AGEC 528 is Emiliano Lopez Barrera. Emiliano has invested a great deal of time and energy in pedagogy for teaching economics to non-economists and helping to guide student projects. Emiliano Lopez Barrera has also adopted the SIMPLE framework for exploration of issues related to nutrition and food waste (Lopez Barrera and Hertel 2020). This course would not have been possible without the collaboration of these three excellent teachers.

I see a number of future opportunities related to this course and the associated materials. First, the development of an explicitly spatial (gridded) version of SIMPLE (SIMPLE on a grid or SIMPLE-G; (Baldos et al. 2020) opens interesting new avenues for teaching and research. Many of the scientists and engineers enrolling in the course have strong geographical information system skills. and the issues in which they are interested (e.g., water scarcity, climate impacts) are inherently geospatial. (It is not interesting to think about water scarcity at the national level—on average the United States, for example, has plenty of water!) Allowing the students to use the gridded model opens the door for more meaningful projects and greater opportunity for subsequent publications. However, this does add another layer of computational and analytical complexity to the course. (One of the SIMPLE-G-US models disaggregates the United States into 75,000+ grids cells.) Finding new ways to teach economics with such a gridded modeling approach is a high priority.

There are two promising approaches to using the gridded model in a classroom context. The first involves running the model and mapping results on the NSF-funded GeoHub.[3] This is an open science platform designed to allow users from anywhere in the world to access and run models using NSF's high-performance computing systems. We experimented with this in September 2019 when we ran a short course for an NSF-funded interdisciplinary project.[4] This allowed participants to run the high resolution SIMPLE-G model and map results without downloading extra software and without access to special computers. They were able to do all this on the GeoHub simply via an internet browser. In this case, we had participants go through the AGEC 528 labs (non-gridded model) online before coming to campus for the course.

The second novel approach, which we have been exploring is aimed at facilitating economic analysis of results from the gridded model. When producing results for 75,000+ grid cells, one can draw attractive maps, but it is hard to analyze why impacts in one region of the country differ from those in another. Toward this end, we have developed a "mini-model." This is a small collection of grid cells (perhaps 10 to 20) for which the impacts are found to differ in interesting ways based on the map of results. Once prices for national outputs and inputs are made exogenous, the individual grid cells in SIMPLE-G no longer communicate with one another, and it is possible to independently solve for grid cell level changes in land, water, fertilizer, and other input use, as well as for crop output. If national boundary conditions (i.e., prices in this case) are appropriately "shocked" when solving the mini-model, then the solution for the grid cells will be the same as for the full model. This means that a careful analysis of results and why they differ across grid cells can be undertaken. This is the essence of lab 5 in Table 2 which focuses on the differential impact of changes in irrigation efficiency. In some grid cells, the response to improved irrigation efficiency is to increase water usage while in others, water use for irrigation falls.

[3] https://mygeohub.org/
[4] https://mygeohub.org/courses/sustainability_shortcourse

Over the next five years, in conjunction with a new NSF project (GLASSNET), we will be offering SIMPLE-G short courses for young scientists across a range of disciplines. For these courses, we plan to employ the GeoHub to facilitate online learning as well as online preparation for an onsite course and for computational purposes. We will also endeavor to teach participants the basic principles of economics as they pertain to addressing the global sustainability challenges related to food, land, water, and climate. It is my hope that these experiences will feed back to the graduate classroom, thereby enhancing the learning opportunities for students enrolled in AGEC 528.

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