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Federal Aviation Administration

FINAL PROJECT REPORT

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PART I - PROJECT IDENTIFICATION INFORMATION

1. Institution and Address	2. FAA Program	3. FAA Award Number
Purdue University	Environment and Energy	13-C-AJFE-PU-006
155 South Grant Street West Lafayette, IN 47907-2114	4. Award Period From 2/19/15 To 8/30/16	5. Cumulative Award Amount $110,000.00

6. Project Title

GTAP Model and Database Modification to Better Handle Cropping Changes in the Intensive Margin

PART II - SUMMARY OF COMPLETED PROJECT (For Public Use)

Previously, induced land use change estimates considered only the extensive margin; that is, adding to harvested area by converting forest or pasture to cropland. However, recent data suggests that some of the increase in global harvested area comes from more intensive use of existing cropland, such as double cropping or use of unused land. This project is designed to add to GTAP, a computable general equilibrium model, the capability of including region specific parameters on degree of intensification. In that way, changes on both the intensive and extensive margins can be estimated.

PART III - TECHNICAL INFORMATION (For Program Management Uses)

1. **ITEM** (Check appropriate blocks)	NONE	ATTACHED	PREVIOUSLY FURNISHED	TO BE FURNISHED SEPARATELY TO PROGRAM	
				Check (X)	Approx. Date
a. Abstracts of Theses	X				
b. Publication Citations		X			
c. Data on Scientific Collaborators		X			
d. Information on Inventions	X				
e. Technical Description of Project and Results		X			
f. Other (specify)					

2. Principal Investigator/Project Director Name (Typed)	3. Principal Investigator / Project Director Signature	4. Date
Wallace E. Tyner	Wallace E. Tyner	7/25/17

FAA Form 9550-5 (03-03) Supersedes Previous Edition

Project 13-C-AJFE-PU-006
GTAP Model and Database Modification to Better Handle Cropping Changes on the Intensive Margin

Purdue University

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Project Funding Level

FAA project funding: $110,000
Cost sharing:
National Biodiesel Board $17,170
Renewable Fuel Foundation $55,000
University of Illinois $25,000
Purdue University $12,833
Total cost share $110,003

Investigation team (Purdue University):

Principal Investigator: Wallace E. Tyner

Co-PI: Farzad Taheripour

Project Overview

Previously, induced land use change estimates considered only the extensive margin; that is, adding to harvested area by converting forest or pasture to cropland. However, recent data suggests that some of the increase in global harvested area comes from more intensive use of existing cropland, such as double cropping or use of unused land. This project is designed to add to GTAP, a computable general equilibrium model, the capability of including region specific parameters on degree of intensification. In that way, changes on both the intensive and extensive margins can be estimated.

Task – Significantly improve the GTAP model capability to handle land use changes on the intensive margin

Objective(s)

This project will incorporate into the new 2011 GTAP data base as well as the previous 2004 data base the capability to endogeneously determe the extent to thich land use changes occur on the intensive or on the extensive margins. The parameters are calibrated using real world data on changes in cropland cover and harvested area over the period 2003-2013. Econometric analysis will be employed in calibrating the region specific parameters.

Research Approach

Induced or indirect land use change due to biofuel production is often evaluated using what are called computable general equilibrium (CGE) models. One model that has been widely used is the Global Trade Analysis Project (GTAP) model developed at Purdue University [1-9]. This model has been modified to trace allocation of land resources (including forest, pasture and cropland) by country and Agro-ecological Zone (AEZ) at the global scale and to model biofuel industry interaction with other economic activities.

We begin discussion on induced land use changes by explaining the logic behind the land use changes induced by an increase in demand for an agricultural commodity for production of biofuels. When there is an increase in demand for a commodity (e.g., maize, rapeseed, etc.), that demand increase causes an increase in the price of the commodity unless the commodity supply is perfectly elastic.[1] The price increase causes some combination of five market mediated responses:[2]

- With a higher price, consumption normally would fall.
- With a higher price for this commodity, there can be switching among crops so that more of this crop is produced and less of other crops.
- With a higher demand for this commodity, more cropland can be needed to meet that increased demand, and this cropland can come from pasture or forest converted to cropland in the location of the demand increase. This is referred to as a change on the extensive margin.
- With the higher commodity demand, the existing cropland might be farmed more intensively such as via double cropping or irrigation or other investments in increased productivity. This is referred to as a change on the intensive margin. An increase in intensive margin on existing cropland reduces demand for land conversion (from either forest or pasture to cropland).
- With higher demand for this commodity for biofuels, there can be impacts on international trade of the commodity and of other substitution commodities.

We will now review each of these market mediated responses.

Reduced consumption

In virtually all the models used to estimate the responses to what economists call demand shocks, one of the impacts is that with higher prices for the commodity in question, less of it will be consumed, whether it is used as food directly, or as animal feed, which is converted to food. The degree of the reduced consumption depends on the demand and supply elasticities and other parameters in the model being used.

Some have argued that reduced consumption should be excluded from the analysis, and in most models, it is possible to freeze food consumption in order to estimate impacts with no change in food consumption.

Crop switching

When the demand for one crop increases, compared to other crops, there likely will be crop switching towards the crop with the increased demand. In the US, the increased demand for maize for ethanol has led to increased crop area of maize and reduction in area of several other crops.

Land conversion

Another possible market mediated response is to add land to the cropland area by converting pasture or forest to cropland. In other words, the increased demand can be met by crop switching or by adding converted land to total

[1] Perfectly elastic supply would mean that any quantity of the commodity in question can be had for the existing market price. In other words, demand has not impact on price. This condition would rarely, if ever, hold in the real world.
[2] A market mediated response is simply a change in price and production of the directly affected commodity and its close substitutes.

cropland area in the region of the biofuel demand shock. This response is sometimes called direct land use change. It is change in land use at the extensive margin.

Land intensification

Another means of increasing production is through more intensive use of existing cropland. This can happen due to yield increases through investments in increased productivity (such as using improved seeds). It can also happen through investments in irrigation and several other activities. In addition, for some crops and geographic areas, it is possible to switch to double or even triple cropping. Thus, more crops are produced on the same land.

Trade impacts

The fifth possible response is changes in international trade and production of the commodity and its substitutes. For example, if Brazil mandates that sugarcane be used for ethanol production, and Brazil is a large sugar exporter, then international trade of sugar can be impacted. For example, Brazil might use more sugar to produce ethanol and export less sugar. To the extent that Brazil reduces sugar exports, then sugar may be produced in some other country to make up at least part of the difference. Part of the land to produce that addition sugar could come from land converted from pasture or forest. This response is sometimes called indirect land use change. It is also another example of change at the extensive margin.

Model improvements needed

These five responses to the increased demand for the commodity in question happen in real world markets. There are several models that are used to estimate the magnitudes of the different responses. All of the models and model results are uncertain. However, we know with certainty that the market mediated responses are not zero. Researchers who work in estimating the induced land use changes have made considerable progress in improving the models and model parameter estimates, but like many other model estimates (emission factor models for example), we must recognize and attempt to characterize the inherent uncertainty in the estimates.

The greatest weakness in the GTAP model and other CGE models is in their handling of changes on the intensive margin. Part of the reason for this has been lack of data on things like change in irrigated area and double cropping. Recently, the distinction between irrigated and dryland crop production has been added to GTAP [10]. It is now possible to estimate the extent to which new production demands might be met with irrigation.

However, double cropping is not something that has been explicitly included in GTAP or other similar models. Recent work by Babcock and Iqbal [11] has provided estimates of the extent to which the increase in global harvested area has come from double cropping (a factor which affects the intensive margin significantly) and the extent to which it has come from land conversion. This work was made possible by the substantial increase in global harvested area (about 40 million hectares) since 2006 [12, 13]. What Babcock and Iqbal did was to try to estimate what fraction of that increase was due to double (or triple) cropping. They concluded that a substantial portion of the increase was from double cropping.

Proposed research

What we propose to do is to add to GTAP the capacity to handle much better this part of the intensive margin. GTAP currently has a parameter called YDEL, which is a yield price elasticity [14]. The current global default value for this parameter is 0.25, which means that, everything else being equal, a 10% increase in net returns to a crop would lead to a 2.5% yield increase. This response is deemed to be a medium term response, so it can include a wide range of technology improvements including improved drainage, higher yielding seeds, better machinery, etc.

There is currently no parameter or module in GTAP of handling the increase in double cropping we have observed since 2006. There is a parameter in GTAP called ETA, which measures the ratio of the productivity of marginal land (land not currently in cropland) to existing cropland. Previously, a value of .67 was used globally. That is, the assumption was that productivity of newly converted land would be two-thirds that of existing cropland. Taheripour and Tyner [9] changed this assumption and calculated ETA values by agro-ecological zone (AEZ) and country making use of estimates of net primary productivity of existing cropland and non-cropland areas by AEZ and country. There are 18 AEZs in GTAP representing agricultural production potential base on climate and soil variables.

What we propose to do here is somewhat similar to the above described work on ETA. We will introduce a new regionalized parameter to explicitly introduce double cropping into the GTAP data base. This parameter named Gamma specifies the degree of increase in harvested area or conversion of unused land by region than has occurred in recent history. Thus, we would be able to calibrate the model to the actual experience in changes in planted area over the past decade.

The impact of these changes will, of course, be to reduce the estimates of induced (direct plus indirect) land use change. The new estimates will be more accurate as they will incorporate the changes we have observed in double cropping over the past decade. The new version of the model will do a much better job of handling changes at the intensive margin. The changes will add double cropping calibration by region to the existing yield price elasticity and irrigation responses.

Milestone(s)

September 2015	Draft report on model and data base modification
December 2015	Complete extensive testing and validation (actually done in March 2016)
August 2016	Completion of final model and analysis.

Major Accomplishments

The model and data base modification were completed, and the new model is now functional and has been used in two publications as well as in work for the ICAO Alternative Fuels Task Force.

Publications

Taheripour, F., Cui, H., & Tyner, W. E. (2017). An Exploration of Agricultural Land use Change at the Intensive and Extensive Margins: Implications for Biofuels Induced Land Use Change. In Z. Qin, U. Mishra, & A. Hastings (Eds.), *Bioenergy and Land Use Change*: American Geophysical Union (Wiley)

Taheripour, F., & Tyner, W. E. (2017). The Impact of Considering Land Intensification and Updated Data on Biofuels Land Use Change and Emissions Estimates. *Biotechnology for Biofuels, 10*(191). doi:10.1186/s13068-017-0877-y

Outreach Efforts

This research has been presented at a Department of Energy Aviation Biofuels Workshop as well as another national biofuels conference.

Awards

Wallace Tyner was named a Fellow of the American Association for the Advancement of Science in 2016.

Student Involvement

There was a PhD student, Xin Zhao, involved in this research as well as a post doc, Hao Cui.

Plans for Next Period

None – this is the project completion report.

References

1. Hertel, T., A. Golub, A. Jones, M. O'Hare, R. Plevin, and D. Kammen, *Effects of US Maize Ethanol on Global Land Use and Greenhouse Gas Emissions: Estimating Market-mediated Responses.* Bioscience, 2010. 60(3): p. 223-231.
2. Hertel, T. and W.E. Tyner, *Market-mediated Environmental Impacts of Biofuels.* Global Food Security, forthcoming 2013.
3. Hertel, T.W., ed. *Global Trade Analysis: Modeling and Applications*. 1997, Cambridge University Press: New York.
4. Taheripour, F., T.W. Hertel, and W.E. Tyner, *Implications of biofuels mandates for the global livestock industry: a computable general equilibrium analysis.* Agricultural Economics, 2011. 42: p. 325–342.
5. Taheripour, F., et al., *Biofuels and their by-products: Globla economic and environmental implications.* Biomass and Bioenergy, 2010. 34(3): p. 278-289.
6. Taheripour, F. and W.E. Tyner, *Biofuels and Land Use Change: Applying Recent Evidence to Model Estimates.* Applied Sciences 2013. 3: p. 14-38.
7. Taheripour, F. and W.E. Tyner, *Induced Land Use Emissions due to First and Second Generation Biofuels and Uncertainty in Land Use Emission Factors.* Economics Research International, 2013(Article ID 315787): p. 12.
8. Taheripour, F. and W.E. Tyner, *Welfare Assessment of the Renewable Fuel Standard: Economic Efficiency, Rebound Effect, and Policy Interactions in a General Equilibrium Framework*, in *Modeling, Dynamics, Optimization and Bioeconomics I, Springer Proceedings in Mathematics & Statistics 73*, A. Pinto and D. Zilberman, Editors. 2014, Springer-Verlag: Switzerland. p. 613-632.
9. Taheripour, F., et al., *Biofuels, cropland expansion, and the extensive margin.* Energy, Sustainability and Society, 2012. 2(25).
10. Taheripour, F., T. Hertel, and J. Liu, *Role of Irrigation in Detrminining the Global Land Use Impacts of Biofuels.* Energy Sustainability and Society, 2013. 3(4): p. 1-18.
11. Babcock, B.A. and Z. Iqbal, *Using Recent Land Use Changes to Validate Land Use Change Models, Staff Report 14-ST 109*, in *Staff Report*, I.S.U. Center for Agricultural and Rural Development, Editor. 2014, Iowa State University: Ames, Iowa.
12. Taheripour, F., C. Hurt, and W.E. Tyner, *Livestock industry in transition: Economic, demographic, and biofuel drivers.* Animal Frontiers, 2013. 3(2): p. 38-46.
13. Tyner, W.E., *Biofuels and food prices: Separating wheat from chaff.* Global Food Security, 2013. 2: p. 126-30.
14. Keeney, R. and T.W. Hertel, *Indirect Land use Impacts of US Biofuels Policies: The Importance of Acreage, Yield and Bilateral Trade Responses.* American Journal of Agricultural Economics, 2009. 91: p. 895-909.