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Global Implications of U.S. Biofuels Policies in an Integrated Partial and General Equilibrium Framework

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Abstract

With the increasing research interests in biofuels, global implications of biofuels production have been generally examined either in a partial equilibrium (PE) or general equilibrium (GE) frameworks. Though both of these approaches have unique strengths, they also suffer from many limitations due to complexity of addressing all the relevant aspects of biofuels. In this paper we have exploited the strengths of both PE and GE approaches for analyzing the economic and environmental implications of the U.S. policies on corn-ethanol and biodiesel production. In this study, we utilize the Forest and Agricultural Sector Optimization Model (FASOMGHG: Adams *et al*. 1996, 2005; Beach *et al*. 2009), a non-linear programming, PE model for the United States. We also use the GTAP-BIO model (Birur *et al*. 2008), a multi-region, multi-sector CGE model for global-scale assessment of biofuels policies. Following Britz and Hertel (2009), we link the GTAP-BIO model through a static, quadratic restricted revenue function obtained from perturbing crop prices from the FASOMGHG model. With this linkage we implement the U.S. Corn ethanol and biodiesel scenarios in the GTAP-BIO model and obtain the FASOMGHG-consistent, global land use changes. The resulting crop price changes from the GE model are fed back into the FASOMGHG model to obtain the disaggregated impacts in the U.S.

Key Words: Biofuels, Indirect land use change, Land use emissions, Partial Equilibrium, Computable General Equilibrium.

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Introduction

As U.S. biofuels policies gain unprecedented attention from researchers, several studies in the recent past have been undertaken either in partial equilibrium (PE) or general equilibrium (GE) frameworks. Although both of these approaches have their own strengths, they also shoulder many caveats due to the complexity of addressing all the relevant aspects related to assessing the impacts of biofuels. For instance, PE models could offer greater depth of analysis due to finely disaggregated sectors. However, PE models alone are insufficient as they do not capture inter-industry and macro-economic implications of a policy. For example, a biofuel renewable fuel standard (RFS) could raise the price of liquid fuels, thereby reducing overall consumption. A biofuel policy might also interact with agricultural, non-agricultural or tax policies, much of which PE models might be hard-pressed to account for. Also, PE models fail to address the linkages between factor income and expenditure resulting from a policy.

On the other hand, global GE models capture interactions in multiple markets on a global scale, simultaneously verifying theoretical as well as accounting consistency. Nevertheless, due to their complex structure and aggregation, GE models do not provide detailed sectoral analysis. Since the currently commercialized first generation biofuels are produced mainly from agricultural sources and compete for land, several recent studies (e.g., Searchinger *et al*. 2008; Hertel *et al.* 2010a, 2010b) have reported that these biofuels could lead to significant implications for global greenhouse gas (GHG) emissions from land use and land cover change that need to be taken into account. Since these studies are based on either PE or GE approaches, they suffer from the limitations discussed above. Keeping this in view, the objective of this paper is to exploit the strengths of both PE and GE approaches for analyzing the economic and environmental implications of U.S. biofuel policies in a more comprehensive way.

Given the relative shortcomings of the PE and GE framework, several studies in the recent past have emphasized on overcoming these limitations by linking the two approaches. For instance, Grant *et al*. (2007) studied the impact of tariff rate quota liberalization on disaggregated U.S. dairy industry in a PE-GE framework. Their study revealed that the use of GE model alone understated the aggregated impacts compared to the sub-sector level analysis using the PE-GE approach. Similarly, Narayanan *et al*. (2010) emphasize on the advantage of PE-GE approach in the GTAP framework for examining the impacts of multilateral tariff liberalization on a structurally diverse India's automotive industry. Those authors reported that use of PE model alone overestimates the disaggregated impacts of tariff liberalization, while the GE model diminishes the impacts on aggregated sectors, leading to mixed policy implications. Whereas, the same trade policy experiments have resulted in realistic sectoral impacts in their PE-GE linked model.

Britz and Hertel (2009) recently adopted a combined PE and GE approach for analyzing the impact of European Union biofuel policies. Those authors combined a PE model of the European Union with a focus on agricultural policy (CAPRI: Britz and Witzke, 2008) with a global GE model on biofuels (GTAP-BIO: Birur *et al*. 2008) and estimated the global as well as detailed regional implications of the EU biofuel policies. We pursue a similar approach but apply this method to the analysis of U.S. biofuel policy. We use the Forest and Agricultural Sector Optimization Model (FASOMGHG: Adams *et al.*, 1996, 2005; Beach *et al*. 2009), a dynamic, partial equilibrium, non-linear programming model in which the United States is divided into 63 sub-regions for agricultural production and 11 market regions. The FASOMGHG includes numerous refined groupings of agricultural and forest commodities covering both first and second generation biofuels. The model tracks land use transition across agriculture, pasture, and forestry uses, accounting for conversion costs reflecting activities such as land clearing, site preparation, etc. The land allocation decision is made based on the net present value of returns at a given price equilibrium.

In addition to accounting for detailed information on U.S. agricultural commodities and policies, the FASOMGHG model also tracks GHGs such as CO_2, CH_4, and N_2O released from agricultural activities. The model is also capable of tracking the application of nitrogen, phosphorus, pesticides, and irrigated water. The dynamic nature of the model allows for tracking carbon sequestration and carbon losses over 70-100 years on a 5-year time step basis. However, it does not account for interactions between factor and commodity markets and has limited connections to the global economy. There are import and export supply and demand equations for major agricultural and forest products commodities important for U.S. trade, but the model does not explicitly model regions outside the U.S. or sectors outside of the forest and agricultural sectors. Thus, in this study, we link the supply-side of FASOMGHG with a global GE model to incorporate feedback effects of market changes in other regions and commodities.

The Global Trade Analysis Project (GTAP) model (Hertel, 1997), a multi-region, multi-sector computable general equilibrium model, is widely used for global-scale assessment of economic policies. A version of this model named GTAP-BIO (Birur *et al.*, 2008) includes the first generation biofuels (grain ethanol, sugar ethanol, and biodiesel) which are allowed to substitute for petroleum products at the firms' production and household consumption level. Along with biofuels, the GTAP-BIO model has 20 other aggregated sectors of the global economy and 18 global regions aggregated based on version 6 of the GTAP data base

(Dimaranan, 2006), which is consistent with the 2001 global economy. Another unique feature of the GTAP-BIO model is the treatment of land endowment which is classified based on 18 agro-ecological zones (AEZs) in each region. This AEZ classification based on soil moisture and temperature conducive to plant growth helps in accounting for heterogeneity of land in each region (Lee *et al*. 2005). Since the GTAP model covers the global economy, we can establish the linkage of agricultural sectors in the FASOMGHG model with the non-agricultural sectors through the GTAP model.

In line with Britz and Hertel (2009), we link the highly refined multi-crop agricultural supply side of the FASOMGHG model with that of the GTAP-BIO model via a static, restricted revenue function. This function is estimated by perturbing prices for crops while holding livestock and forestry activities fixed. The resulting responses are used to fit a normalized quadratic restricted revenue function, which is then incorporated into the GTAP model. This model is solved to obtain FASOMGHG-consistent, global land use changes owing to corn-ethanol and biodiesel mandates. The disaggregated national impacts are obtained by feeding these price changes back into the FASOMGHG model. Results are compared to the EPA findings which have utilized FASOMGHG, FAPRI and GTAP models, in various combinations, but never with this kind of internal consistency imposed.

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Table A1. Mapping of FASOMGHG and GTAP crop sectors.

FASOMGHG crop sectors	GTAP crop sectors	GTAP-BIO sectors
Corn, Oats, Oats for grazing, Barley, Rye, Rye for grazing, Rye grazed out, Sorghum, Sweet sorghum.	Cereal grains (gro)	Coarse Grains
Soft white wheat, Hard red winter wheat, Durham wheat, Hard red spring wheat, Wheat for grazing, Durham wheat with residue, Rice.	Paddy rice (pdr), wheat (wht)	Other Grains
Soybeans	Oilseeds (osd)	Oilseeds
Sugarcane, Sugar beet	Sugar-cane & beet (c_b)	Sugar crops
Cotton, Silage, Hay, Potatoes, Tomato for fresh market, Tomato processing, Switchgrass, Orange for fresh market, Orange for processing, Grapefruit for fresh market, Grapefruit for processing, Improved pasture.	Vegetables & Fruits (v_f), Other crops (ocr), Plant fibers (pfb)	Other Agri

Table A2. Regional Aggregation in GTAP-BIO and FASOMGHG Models

Aggregated Global Regions in the GTAP-BIO Model			U.S. Regions in the FASOMGHG Model		
1	USA	United States of America	1	CB	Corn Belt
2	CAN	Canada	2	GP	Great Plains (no forestry)
3	EU27	European Union-27	3	LS	Lake States
4	BRAZIL	Brazil	4	NE	Northeast
5	JAPAN	Japan	5	RM	Rocky Mountains
6	CHIHKG	China-Hong Kong	6	PSW	Pacific Southwest
7	INDIA	India	7	PNWW	Pacific Northwest west side (no agriculture)
8	LAEEX	Latin American Energy Exporters	8	PNWE	Pacific Northwest east side
9	RoLAC	Rest of Latin America & Caribbean	9	SC	South Central
10	EEFSUEX	Eastern Europe & Former Soviet Union Energy Exporters	10	SE	Southeast
11	RoE	Rest of Europe	11	SW	South West (no forestry)
12	MEASTNAEX	Middle Eastern North Africa energy exporters			
13	SSAEX	Sub Saharan Energy exporters			
14	RoAFR	Rest of North Africa & Sub-Saharan Africa			
15	SASIAEEX	South Asian Energy exporters			
16	RoHIA	Rest of High Income Asia			
17	RoASIA	Rest of Southeast & South Asia			
18	Oceania	Oceania countries			

Table A3. Acreage and Revenue Share of U.S. Crops in the FASOMGHG model classified under GTAP-BIO Categories (2000).

Coarse Grains

Crops	*Acreage Share (%)*	*Revenue Share (%)*
Corn	76.16	86.64
Oats	3.85	2.46
Oats Grazing	1.64	0.00
Barley	7.41	3.84
Rye	0.93	0.24
Rye Grazing	0.93	0.00
Rye Graze Out	0.10	0.00
Sorghum	8.98	6.82
Sweet Sorghum	0.00	0.00

Other Grains

Crops	*Acreage Share (%)*	*Revenue Share (%)*
Soft White Wheat	2.77	3.28
Hard Red Winter Wheat	15.91	66.76
Durham Wheat	4.36	2.15
Hard Red Spring Wheat	25.28	17.34
Wheat Grazing	47.43	0.00
rDurham Wheat	0.00	0.00
Rice	4.25	10.46

Oilseeds

Crops	*Acreage Share (%)*	*Revenue Share (%)*
Soybeans	100	100

Other Agri

Crops	*Acreage Share (%)*	*Revenue Share (%)*
Cotton	16.96	0.13
Silage	9.07	7.50
Hay	70.44	59.38
Potatoes	1.56	12.35
Tomato Fresh	0.14	5.53
Tomato Proc	0.36	2.54
Switch Grass	0.00	0.00
Orange Fresh	0.22	2.18
Orange Proc	0.62	4.68
Grape Fruit Fresh	0.09	5.17
Grape Fruit Proc	0.10	0.53
Improved pasture	0.44	0.00

Sugar Crops

Crops	*Acreage Share (%)*	*Revenue Share (%)*
Sugarcane	34.16	38.71
Sugar beet	65.84	61.29