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March 2008

Working Paper # 08005

Department of Economics Working Papers Series

Ames, Iowa 50011

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Land Allocation Effects of the Global Ethanol Surge: Predictions from the International FAPRI Model

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This draft: March 3, 2008

Abstract: We quantify the emergence of biofuel markets and its impact on U.S. and world agriculture for the coming decade using the multi-market multi-commodity international FAPRI model. The model incorporates the tradeoffs between biofuel, feed, and food production and consumption and international feedback effects of the emergence through world commodity prices and trade. We examine land allocation by type of crop, and pasture use for countries growing feedstock for ethanol (corn, sorghum, wheat, sugarcane, and other grains) and major crops competing with feedstock for land resources such as oilseeds. We shock the model with exogenous changes in ethanol demand, first in the United States, then in Brazil, China, EU, and India, and compute shock multipliers for land allocation decisions for crops and countries of interest. The multipliers show at the margin how sensitive land allocation is to the growing demand for ethanol. Land moves away from major crops and pasture competing for resources with feedstock crops. Because of the high U.S. tariff on ethanol, higher U.S. demand for ethanol translates into a U.S. ethanol production expansion. The latter has global effects on land allocation as higher coarse grains prices transmit worldwide. Changes in U.S. coarse grain prices also affect U.S. wheat and oilseeds prices, which are all transmitted to world markets. In contrast, expansion in Brazil ethanol use and production chiefly affects land used for sugarcane production in Brazil and to a lesser extent in other sugar-producing countries, but with small impact on other land uses in most countries.

Keywords: Acreage, area, biofuel, corn, crops, ethanol, FAPRI model, feedstock, land, sugar, sugarcane.

JEL Code: Q42, Q17, Q15

* Early drafts of this paper were presented at the Farm Foundation workshop, "Biofuels Food and Feed Tradeoffs" in April 2007 in Saint Louis, Missouri, and the OECD conference "Modelling Global Land Use and Social Implications in the Sustainability Assessment of Biofuels" in June, 2007 in Copenhagen, Denmark. Affiliations are as follows: Fabiosa, Elobeid, Dong, Tokgoz and Yu, Center for Agricultural and Rural Development and Economics Department at Iowa State University; Beghin, Economics Department at Iowa State University, and Economic Discipline at The University of Sydney. Contact Author: Beghin, 260 Heady Hall, ISU, Ames IA 50011-1070. USA. Email: Beghin@iastate.edu. Phone: 1 515 294 5811. Fax: 1 515 294 6336.We thank Bruce Babcock, Chad Hart, Dermot Hayes, Patrick Westhoff, and conference participants for discussions and comments on the analysis.

1. Introduction

The global emergence of biofuel production is bringing forth new trade-offs between food, feed, energy, and the environment. These trade-offs are multi-dimensional, with both local and global implications (Elobeid et al. (2007); Farrell et al. (2006); Hill et al. (2006); Secchi, and Babcock (2007); and Walsh, et al. (2003)). Our paper sheds light on several dimensions of these trade-offs with a focus on land allocation. We explore how significant the trade-offs are and where they occur in terms of geographical and market location (land use, commodity, and processed food markets). Our investigation of the land allocation effects of the biofuel emergence pays particular attention to ethanol production expansion, its effects on land devoted to feedstock, and competing crops.

In particular, we focus on ethanol expansion in the United States, Brazil, China, EU, and India. Brazil and the United States are the world's largest ethanol producers and markets. Brazil is the only significant exporter of ethanol. The other three countries (China, EU, and India) also have significant ethanol markets. These five countries constitute the bulk of the world ethanol market. Biodiesel is the other major existing biofuel, but biodiesel is currently unprofitable and its expansion is much less likely. The latter motivates our focus on ethanol. An expansion of ethanol production and/or consumption in these five countries has significant local land allocation effects that propagate globally through world trade and price effects. The latter induce land re-allocation away from crops for which relative prices fall and towards crops for which relative prices rise. As competition for land intensifies, aggregate land use in crop production is expected to increase. We examine the projected evolution of land allocation under this biofuel emergence by type of crop, and pasture use for key countries growing feedstock for ethanol (corn, sorghum, wheat, sugarcane, and other grains) and major crops competing with feedstock for land resources such as oilseeds.

Our analysis relies extensively on the international FAPRI model, a multi-market partial-equilibrium model of world agriculture, food, fiber, and bioenergy markets. We use the international FAPRI model to quantify a sequence of two ethanol shocks: first, an exogenous increase in U.S. ethanol demand, and then an exogenous increase in world demand for ethanol (Brazil, China, EU, and India). We compute the effects of these two shocks in deviation from the 2007 U.S. and world FAPRI baseline for the years 2007/08 to 2016/17 (FAPRI, 2007). To compare the shocks, we compute proportional impact multipliers on key variables (*dln(variable)/dln(shock)*) and report their values summarized in the 10-year average. The variables of prime interest are land, prices, trade, and production and consumption effects. The land multipliers show at the margin how sensitive (or not) land allocation is to the growing demand for ethanol, not only in countries with sizeable ethanol markets, but also in other countries growing feedstock crops and crops competing for land with the latter. We highlight the movement of land away from major crops competing for land with feedstock crops. Because of the high U.S. tariff on ethanol, the U.S. and world ethanol markets are nearly segmented.

Higher U.S. demand for ethanol only translates into a U.S. ethanol production expansion with little ethanol expansion elsewhere. However, this U.S. expansion has strong global effects on land allocation as coarse grains prices transmit significant shocks worldwide. Changes in U.S. coarse grain prices also affect the price of U.S. wheat and oilseeds through land shifting away from the latter. These price increases also transmit to world markets. In contrast, an expansion in Brazilian ethanol use and production chiefly affects the world ethanol market and land used for sugarcane production in Brazil, and to a lesser extent, in other sugar-producing countries. However, the Brazilian expansion has a small impact on other land uses in most other countries as sugar crops tend to compete less for land than corn and coarse grains do.

In the next section, we locate our paper in the existing literature on biofuels. Then, we provide a non-technical description of the international FAPRI model. Next, we describe the shocks to the models and the simulations results. The final section presents the conclusions.

Recent Literature on Biofuels

There are a growing number of studies on ethanol and other biofuel markets, as the industry has experienced a boom only in recent years. The contributions of De La Torre Ugarte et al. (2003), Elobeid and Tokgoz (forthcoming), Elobeid et al. (2007), English et al. (2001, 2004, 2006a, and 2006b), Gallagher, Otto, and Dikeman (2000), Gallagher et al. (2003 and 2006), House et al. (1993), Tokgoz and Elobeid (2006), Tokgoz et al. (2007), USDA-OCE (2000 and 2002), and Walsh et al. (2003) stand out. Gallagher et al. (2006) look at the competitive position of Brazilian ethanol produced from sugar processing vis-à-vis the U.S. ethanol produced from corn under the assumption of no tariffs in the ethanol market. Koizumi and Yanagishima (2005), one of the first to establish an international ethanol model, examine the implications of a change in the compulsory ethanol-gasoline blend ratio in Brazil on world ethanol and sugar markets.

Few papers fully endogenize the prices of major feedstock crops used in ethanol production (sugar and corn). Most studies have held these constant (Gallagher et al., 2006; Koizumi and Yanagishima, 2005), with the exception of Ferris and Joshi (2005). Recently, Elobeid and Tokgoz (forthcoming), and Tokgoz and Elobeid (2006) have endogenized these crop prices using a large set of models including the international crop markets and explicit market equilibrium mechanisms. These recent studies of Elobeid and Tokgoz incorporate linkages between an international ethanol model, an international sugar model, and a U.S. crops model. FAPRI (2007) and Tokgoz et al.

(2007) incorporate model developments proposed by Elobeid and Tokgoz and represent the first attempt to fully endogenize all major prices through explicit modeling of world markets for ethanol, feedstock crops, and other agricultural commodities.

Elobeid and Tokgoz (forthcoming) also analyze the impact of ethanol trade liberalization and removal of the federal tax credit in the United States on U.S. and Brazilian ethanol markets. The U.S. tariff insulates the U.S. producers from most of the world market discipline. The removal of ethanol trade distortions induces an increase in the price of world ethanol and jolts the U.S. ethanol market. The U.S. domestic ethanol price decreases, which results in a significant decline in production and an increase in consumption through larger imports. Brazil responds to the higher world ethanol price by increasing its production. Total ethanol consumption in Brazil decreases and net exports increase. Tokgoz and Elobeid (2006) analyze the impact of price shocks in three input and output markets critical to ethanol: gasoline, corn, and sugar. They investigate the impact of these shocks on ethanol and related agricultural markets in the United States and Brazil. They find that the composition of a country's vehicle fleet determines the direction of the response of ethanol consumption to changes in the gasoline price. They also find that a change in feedstock costs affects the profitability of ethanol producers and the domestic ethanol price. In Brazil, where ethanol and sugar compete for the supply of sugarcane, changes in the sugar market affect the competing ethanol market and price.

English et al. (2006a) look at the impact of achieving the goal of "25x25" (25% of the projected energy needed in 2025 coming from renewable energy sources) on the U.S. agricultural sector. They use a computer simulation model of U.S. agriculture, which provides annual estimates of changes in U.S. land use resulting from the demand generated by bioenergy industries. This comprehensive study of the U.S. agricultural sector abstracts from impacts of the changes in the U.S. agricultural sector on international agricultural markets and the resulting adjustments on world prices. English et al. (2006b) analyze similar issues using the same model for a shorter time horizon (2014) and focus on the southern region of the United States.

The various analyses by English, De la Torre, and associates (De La Torre Ugarte et al., 2003; English et al., 2006a, 2006b; Walsh et al., 2003) have been outstanding, but have overstated the competitiveness of cellulosic feedstock in ethanol production. Most recent estimates (e.g., Popp and Hogan, 2007) provide unit cost of cellulosic feedstock nearly twice as large as the original ones (e.g., Hallam, Anderson, and Buxton (2001)). The new estimates clearly suggest that cellulosic ethanol is not competitive at current market conditions. In our analysis, we also abstract away from cellulosic-ethanol expansion to reflect its lack of competitiveness.

The International FAPRI Model

Model structure

The international FAPRI model is a set of multi-market (multi-commodity, multi-country) partial-equilibrium models developed at Iowa State University. The international FAPRI model includes econometric and simulation sub-models covering all major temperate crops, sugar, ethanol, dairy, and livestock and meat products for all major producing and consuming countries and calibrated on most recently available data (see Table 1 for commodity and country coverage). The international FAPRI model is used extensively for market outlook and policy analysis (FAPRI (2007)). Extensive market linkages exist in the model, reflecting derived demand for feed in livestock and dairy sectors, competition for land in production, and consumer substitution possibilities for close substitutes such as vegetable oils and meat types. The international FAPRI model and associated numerical analyses have been validated through numerous academic publications, external reviews, and internal annual updates.

<Table 1 about here>

The modeling system captures the biological, technical, and economic relations among key variables within a particular commodity and across commodities. The model is based on historical data analysis, current academic research, and a reliance on accepted economic, agronomic, and biological relationships in agricultural production and markets.

In general, for each commodity sector, the economic relationship that supply equals demand is maintained by determining a market-clearing price for the commodity. In countries where domestic prices are not solved endogenously, these prices are modeled as a function of the world price using a price transmission equation. Since the sub-model for each sector/commodity is linked to the other sub-models, changes in one commodity sector impacts other sectors. Agricultural supply comes from land harvested multiplied by yields. Land responds to relative agricultural prices reflecting the competition for land among crops within defined geographical areas. Oilseeds and grains compete for land in many countries. Within grains, corn and other coarse grains compete as well for land. Sugarcane production is often on land unsuitable for other crops, yet it competes with soybeans in Brazil, and rice in some Asian countries.

We turn to the structure of the ethanol sub-model. Like the other FAPRI sub-models, the ethanol sub-model is a non-spatial, multi-market world model. The sub-model specifies ethanol production, use, and trade between countries/regions. Country coverage consists of the U.S., Brazil, EU-25, China, India, Japan, South Korea, and a Rest-of-World aggregate. The model incorporates linkages to the agriculture and energy markets, namely, feedstock crops, world sugar, and gasoline markets.

The general structure of the country ethanol model is made up of behavioral equations for production, consumption, stocks, and net trade. Complete country models are established for the U.S., Brazil, China, EU-25, and India, while only net trade equations are set up for Japan, South Korea, and the Rest-of-World because of limited data availability. The model solves for a representative world ethanol price (Brazilian anhydrous ethanol price) by equating excess supply and excess demand across countries. Using price transmission equations, the domestic price of ethanol for each country is linked with the representative world price through exchange rates and other price policy parameters. All prices in the model are expressed in real terms. U.S. ethanol is produced primarily from corn predominantly from a dry-milling process with dried distillers grains (DDG) as a major byproduct. The U.S. ethanol market is nearly insulated from the world ethanol market, because of a high U.S. tariff imposed on non-preferential imports of ethanol. Some limited imports occur through the Caribbean Islands[1] but these do not threaten the protection of U.S. producers. Brazilian ethanol is produced from sugarcane. Indian ethanol is produced from molasses. EU ethanol production uses a combination of grains as feedstock. The structure of the U.S. component of the ethanol sub-model is more elaborate, especially on the ethanol demand side. As these demand characteristics have limited implication for land use, we refer interested readers to Elobeid and Tokgoz (forthcoming) for further information. Further description of the FAPRI model is available on the internet at http://www.fapri.iastate.edu/models/.

Data and calibration

The model is calibrated on 2006/07 marketing year data for crops and 2006 calendar year data for livestock and biofuels, and 10-year projections are generated for the period

[1] The U.S. ethanol trade policy includes a 2.5 percent ad valorem tariff and a per unit tariff of 54¢ per gallon. However, under Caribbean Basin Economic Recovery Act (CBERA), if ethanol is produced from at least 50 percent agricultural feedstock grown in a CBERA country, it is admitted into the U.S. free of duty.

between 2007 and 2016. The sub-models also adjust for marketing-year differences by including a residual that is equal to world exports minus world imports, which ensures that world demand equals world supply. Elasticity values for supply and demand responses are based on econometric analysis and on consensus estimates.

Agricultural and trade policies for each commodity in a country are included in the sub-models to the extent that they affect the supply and demand decisions of the economic agents. These include taxes on exports and imports, tariffs, tariff rate quotas, export subsidies, intervention prices, other domestic support instruments, and set-aside rates. The models assume that existing agricultural and trade policy variables will remain unchanged in the outlook period. Elasticity parameters estimates and policy variables used in the model are available at http://www.fapri.iastate.edu/tools/.

Data for commodity supply and utilization are obtained from the F.O. Lichts online database, the Food and Agriculture Organization (FAO) of the United Nations (FAOSTAT Online, 2006), the Production, Supply and Distribution View (PS&D) of the U.S. Department of Agriculture (USDA), and the European Commission Directorate General for Energy and Transport, and UNICA (2006) among others. Macroeconomic data such as GDP, GDP deflator, population, and exchange rate are exogenous variables that drive the projections of the model. They were gathered from the International Monetary Fund and Global Insight.

These data sets provide historical data that are used to calibrate the models, and the models provide projections for supply and utilization of commodities and prices. Supply and utilization data include land use, yields, production, consumption, net trade, and stocks.

Simulation Scenarios

Baseline scenario

The baseline scenario is the 2007 FAPRI U.S. and World outlook (FAPRI, 2007), which establishes a credible reference trajectory for all variables of interest (land use by country by crop, production, consumption, commodity prices, uses of crops including ethanol feedstock, feed, and food use; and trade flows). The FAPRI baseline assumes continuity in current policies for the coming decade (2007/08 to 2016/17). The baseline includes a significant increase in ethanol production and use with a sustained increase in land allocation to corn in the United States away from soybeans, and toward sugarcane and soybean in Brazil. Detailed information on the FAPRI baseline assumptions and results is posted at http://www.fapri.iastate.edu/outlook2007/.

Scenario 1

In scenario 1, we shock U.S. demand for ethanol with a permanent 10% exogenous annual expansion (horizontal shift of demand) leading to an equilibrium increase in U.S. ethanol use by roughly 3% per year. As the U.S. demand for ethanol is very elastic at the margin, a large shift is necessary to induce a net increase in the equilibrium of the U.S. ethanol market. The mandatory component of ethanol demand is price inelastic but infra marginal. At the margin, ethanol based gasoline competes in price with regular gasoline; a small increase in ethanol price decreases the competitiveness of ethanol-based gasoline and the use of ethanol by refiners falls rapidly at the margin.

The adjustment mechanism to this U.S. shock is first through a direct impact on U.S. ethanol production, then U.S. use and production of coarse grains, chiefly corn, and then other crops. Ethanol imports are little affected, as the U.S. price remains lower than the world price inclusive of the high U.S. tariff and the transportation cost. In the United States, there is a trickle-down of price effects from crude oil to gasoline, to ethanol, to corn to other coarse grains, to other crops, to feed prices, to livestock, etc, which in turn affects these markets and the associated land allocation. The crop price changes freely transmit to the world markets. Since the United States is a major producer and exporter of corn, wheat, sorghum, and soybeans, any changes in the U.S. price of these commodities affect the world markets to a great extent. The higher U.S. ethanol price does not transmit to the world ethanol market as the two ethanol markets are effectively segmented by the large U.S. ethanol tariff.

We compute annual proportional impact multipliers on key variables in proportional deviation from the baseline (*dln(variable)/dln(US ethanol use)*) and report their values summarized in the 10-year average. These are shown for key variables in the first row of Table 2 under each country label. The multipliers can be interpreted as indicating the average annual percent change in a variable induced by a 1% increase in U.S. ethanol use. The variables shown are ethanol output and trade, world and U.S. ethanol prices, land area and world price of corn, sugar beet, sugarcane, feed grains, wheat, soybean, rapeseed/canola, and sunflower. The countries reported in Table 2 are Brazil, China, the EU-25, India, U.S. as ethanol producing countries, and Argentina, Australia, Canada, Mexico, and South Africa for non-ethanol producing countries, and a world aggregate.

Scenario 2

Scenario 2 considers a permanent 5% exogenous annual increase of ethanol demand (horizontal shift of demand) in Brazil, China, the EU-25, and India, leading to an equilibrium increase in aggregate ethanol use in these countries of roughly 3%. We compute a second set of impact multipliers for 2007/08 to 20016/17 in deviation from the baseline values (*dln(variable) / dln(aggregate ethanol use in Brazil, China, EU, and India)*) and again we report their values summarized in the 10-year average. The interpretation of these multipliers is similar to the former one (percent change in variable induced by a 1% change in aggregate ethanol demand in these four countries). They appear in the second row of Table 2 for each country, below the country results for Scenario 1. Detailed results for all variables and all countries are available from the authors.

<Table 2 about here>

Results

Scenario 1 results

The increase in U.S. ethanol use directly affects U.S. feedstock markets, especially corn, and to a lesser extent, sorghum. U.S. exports of coarse grains decrease --trade has the highest multipliers; stocks are reduced (second largest multipliers), then land devoted to coarse grains expands. Long-term land responses would be higher as adjustment takes time. Substitution possibilities in feed demand for corn contribute to the propagation of higher prices to all feed products (sorghum, barley, oats, and wheat). In the U.S. corn market, the derived demand for feedstock in ethanol production increases by more than one (multiplier value of 1.04) as corn displaces other grains. Corn feed use falls (multiplier value of -0.19) ; seed use increases (0.18) with the expansion of land devoted to corn; and food corn use falls slightly. The most significant drop in food use is in high fructose corn syrup (HFCS) production (-0.06); the multiplier for other-food use is -0.02. In aggregate, total corn use (domestic use) increases but by much less than the initial ethanol (multiplier value of 0.29). Corn exports decrease dramatically (-0.6) and stocks fall substantially (-0.45). U.S. land area allocated to corn increases (0.14); the latter could potentially increase by higher rates in the long run when inventories bottom out at their minimum required levels for markets to function. The impacts on U.S. sorghum and barley are qualitatively similar, but smaller. U.S. land area increases slightly for sorghum (0.035) and more substantially for barley (0.103).

In U.S. oilseed markets, there is a sharp reduction in land devoted to soybean (-0.10) and, to a lesser extent, to sunflower (-0.046). Changes in land allocations to other oilseeds exhibit smaller magnitude in absolute value. These reductions lead to higher oilseed prices with lead to biodiesel production to fall (multiplier value of -0.15). In livestock and meat markets, the ethanol shock translates into higher feed grain prices, lower DDG prices, and a small increase in meal prices. The lower DDG price has to be qualified. The expansion of ethanol production induces a similar expansion in its by-products such as DDGs. Higher DDG supply translates into a lower equilibrium price. Nevertheless, the FAPRI model probably underestimates the substitution possibilities between DDGs and coarse grains. Indeed recent U.S. corn and DDG prices have been nearly confounded. The shock leads to a small reduction in aggregate meat production. Substitution in consumption induces net gains to some sectors. U.S. beef production increases slightly and wholesale meat prices increase moderately. Retail prices increase by even less. The trickle down of price effects is summarized in Figure 1.

The world impact of the U.S. ethanol shock occurs first via preferential ethanol trade expansion. Preferential ethanol imports by the United States increase but from a very small base (multiplier of 0.6). This expansion has a negligible impact on the world ethanol markets except for net trade adjustments, which are large in percentage terms because they are computed from a small base. In terms of feedstock, there are negligible effects on world sugarcane land allocation (0.002) as world sugarcane-based ethanol production does not change much.

By contrast, the higher U.S. feed grain and oilseed prices transmits to other countries, but not fully as tariffs and other trade costs prevent full transmission of world price effects into local markets. World land area devoted to corn increases moderately in aggregate (0.06), but more substantially in Argentina (0.106). Growth in land devoted to corn in Brazil and India follows nearly with the aggregate corn supply (multipliers of 0.05 and 0.059, respectively). Higher world prices for other feed grains also occur. They translate in smaller net imports and larger net exports,, but these effects are more moderate than for corn. Land devoted to other feed grains tends to expand moderately. For example, world sorghum area expands proportionally by about a fourth of the world corn area expansion (multiplier of 0.016 versus 0.06). World soybean land allocation falls slightly (-0.026), but it expands in Brazil, the most competitive soybean producer in the world (0.033). However, soybean land area falls in Argentina in favor of land devoted to corn (soybean multiplier of -0.04). Rapeseed land allocation falls globally (multiplier of -0.02 or less in absolute value). Sunflower land area falls in Argentina (-0.068), but increases in the EU-25 (0.015). As the competition for land increases, there are moderate decreases in pasture land in Brazil and Argentina.

Scenario 2 results

The shock on the world ethanol markets has a direct impact on the world ethanol price, as well as, on the local ethanol markets in which the shock is initiated. The average impact on the world ethanol price is very high (multiplier of 3.11). In sharp contrast, the U.S. ethanol price (Omaha price) is left nearly unaffected (multiplier of 0.01). This lack of impact is motivated by the segmentation of the U.S. and world markets as previously explained. World ethanol trade is impacted and exhibit large multipliers because trade is thin: U.S. imports fall (multiplier of -2.27); Brazilian exports rise despite the exogenous increase in its demand (1.31); and the EU-25 imports sharply respond given the shock imposed on the EU ethanol market and the net importing status of the latter country (multiplier of 8.92). Brazilian ethanol production increases substantially (multiplier of 0.94). By contrast again, U.S. ethanol production and feedstock use are barely affected (multiplier of 0.04). Given the increase in world ethanol price, there is a small decrease in U.S. use via its imported consumption (multiplier of -0.02). Land effects in the United States are even smaller.

In feedstock markets, the largest price effects are registered for sugar given the importance of sugarcane and sugar by products as a feedstock in Brazil and India (sugar price multiplier of 0.13). The effect on world corn prices is a tenth of that on sugar price (0.013), because of the limited size of the grain-based ethanol production outside of the United States, namely in China and the EU. Similarly, the price of other feed grains increases slightly (multiplier of 0.009 or less). The world ethanol shock has some impact on grain stocks and grain trade flows, but land area devoted to grains and grain production remain nearly unchanged in most countries. Feedstock use increases in China (0.75) , EU (0.24), India (molasses) and in Brazil (sugarcane multiplier of 0.94). To summarize, the impact on sugarcane and sugar is the only significant change in feedstock markets. Brazil sugarcane area increases substantially (multiplier of 0.44); sugar production falls as it competes with ethanol for the sugarcane feedstock (-0.11); and sugar exports fall (-0.168). Other competitive sugar exporters expand their land area devoted to sugar crops, production, and exports (multipliers of 0.01 to 0.04). Worldwide, sugarcane land area increases with a multiplier of 0.138, but world sugar output falls as expected but rather slightly (multiplier of -0.012). The impacts on most other crops and sectors are negligible.

Conclusions

This study analyzed and quantified the foreseeable emergence of biofuel markets in the U.S. and world agriculture using the international FAPRI model and two ethanol demand scenarios. We examined the projected evolution of land allocation under this biofuel emergence for major feedstocks and crops, as well as for key countries. We reported the movement of land away from major crops competing for land with feedstock crops.

The major effects of U.S. ethanol expansion on U.S. agriculture occurs through corn prices trickling down to other feed grains, and other crops prices inducing significant U.S. land allocation changes. These price effects also transmit worldwide, especially feed grains and soybean, and thus affect the land allocation in some countries such as Argentina and Brazil. Land allocation effects may be understated in our results because of large stock adjustments occurring in the short term.

U.S. and world ethanol markets are segmented but could be integrated by the removal of the ethanol tariff (free trade). This in turn would reduce the significant corn land area effect of the current U.S. ethanol expansion. Brazilian ethanol producers would perceive the increased profit opportunities on the U.S. market and increase ethanol production to meet the demand, rather than U.S. producers.

The effect of world ethanol expansion is limited to sugarcane and sugar markets because Brazil is the largest and most-competitive ethanol producer and mostly uses sugarcane as feedstock. Sugarcane competes less for land with other crops relative to corn. The resulting impact of a shock in world ethanol demand on U.S. agriculture is negligible, even including the U.S. sugar market because of the insulation of the U.S. sugar and ethanol industries through trade protection. The international shock has impacts on sugarcane land allocation and sugar markets outside the United States and mostly in Brazil.

In sum, the global effects of the biofuel expansion on land are more limited than its local effects on land and other local industries competing for the feedstock. Effects on land re-allocation within countries are sometimes large such as the U.S. corn and soybean reallocation or the grain/oilseed allocation in Latin America.

Given the emerging nature of the world ethanol markets, our study comes with some caveats. Limited data availability for ethanol markets makes econometric estimations of elasticities used in the biofuel model difficult. The scenario results provided here are dependent upon several assumptions, such as the lack of cellulosic ethanol production, the ability of livestock sector to adapt to the use of biofuel co-products in feed rations, and the ability of the world ethanol market to move through supply and demand bottlenecks. As entrepreneurs around the world push for new breakthroughs in biofuel and co-product production and usage, it is possible that some of the assumptions used for this analysis may no longer be relevant.

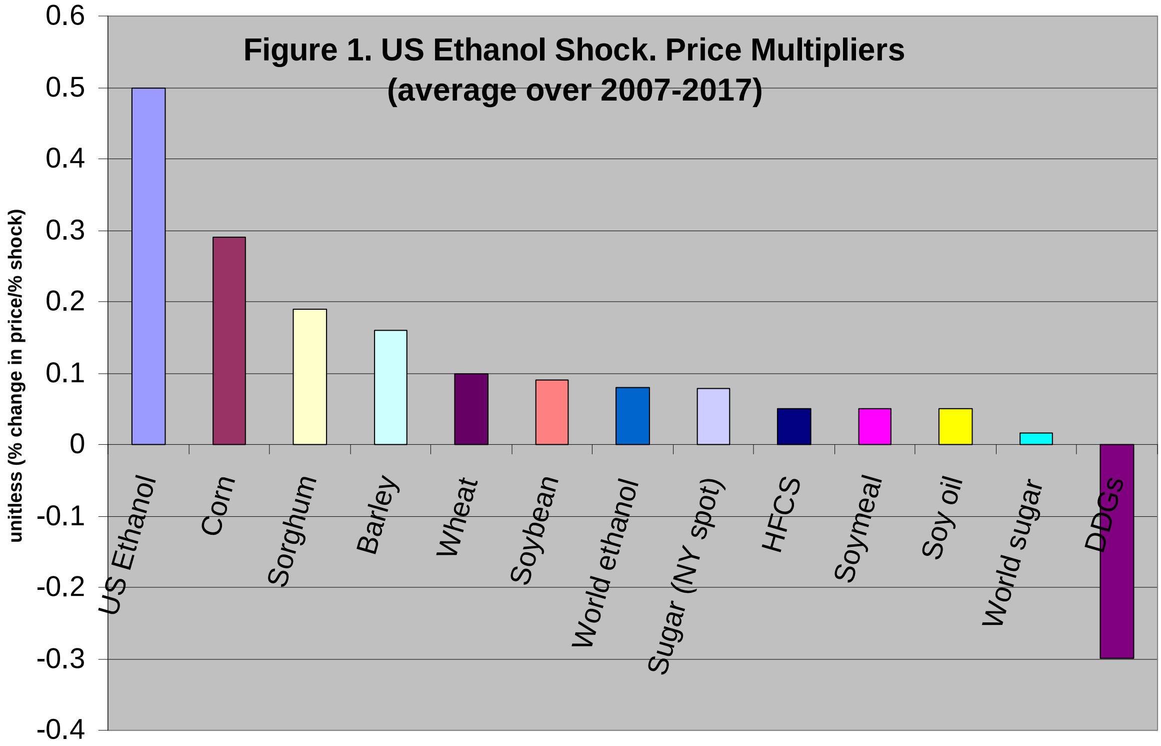
Figure 1. US Ethanol Shock. Price Multipliers
(average over 2007-2017)
unitless (% change in price/% shock)
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
US Ethanol
Corn
Sorghum
Barley
Wheat
Soybean
World ethanol
Sugar (NY spot)
HFCS
Soymeal
Soy oil
World sugar
DDGs

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Table 1. The International FAPRI Model

Exogenous Drivers	Historical Agricultural Data	Commodities	Major Countries/Regions*	Endogenous Variables (by commodity and country)
Population GDP GDP deflator Exchange rate Population Policy variables	Area harvested Yield Production Consumption Exports Imports Ending stocks Domestic prices World prices	Grains: Corn, Wheat, Sorghum, Barley Oilseeds (seed, meal and oil): Soybeans, Rapeseed, Sunflower Palm peanuts Livestock & products: Beef, Poultry, Pork Dairy: Milk, Cheese, Butter, Milk powder Sugar: Beet, Sugarcane, Raw sugar Ethanol Biodiesel	Algeria, Argentina Australia Brazil Canada China Bulgaria&Romania Egypt EU-25 India Indonesia Israel Japan Malaysia Mexico Other Africa Other Asia Other CIS Other Eastern Europe Other Latin America Other Middle East Pakistan Philippines Russia South Africa South Korea Taiwan Thailand Ukraine United States Vietnam Rest of World	World prices Domestic price Production Consumption by use (food, feed, feedstock, seed, crush) Net trade Beginning stocks Ending stocks Land area harvested Yield

*Country coverage varies by commodity. Coverage is shown for corn.

Table 2. Impact Multipliers from Scenarios for Major Variables																						
Multipliers (unitless, 10-year average (percent change in variable/ percent change in ethanol use))																						
Country	**Ethanol demand shock**	**Ethanol output**	**Ethanol trade**	**World ethanol price**	**US ethanol price**	**Corn area**	**World corn price**	**Sugar area (beet)**	**Sugar area (cane)**	**World sugar price**	**Barley area**	**World barley price**	**Sorghum area**	**World Sorghum price**	**Wheat area**	**World wheat price**	**Soybean area**	**World soybean price**	**Canola/ rape area**	**World canola price**	**Sun-flower area**	**World sunflower price**
Ethanol producers																						
Brazil	US	0.009	0.164	0.079	0.560	0.050	0.288	na	-0.002	0.016	0.037	0.157	na	0.191	-0.008	0.107	0.033	0.090	na	0.018	na	0.087
	world	0.941	1.311	3.107	0.014	0.003	0.013	na	0.444	0.131	0.003	0.009	na	0.009	0.000	0.006	0.002	0.005	na	0.004	na	0.006
China	US	-0.017	-0.158			0.023		0.001	0.000		-0.003		na		0.008		-0.011		-0.011		-0.068	
	world	0.754	-2.036			0.001		0.006	0.003		0.000		na		0.001		0.000		0.000		0.000	
EU-25	US	0.006	-0.073			-0.002		0.000	0.000		-0.001		na		-0.002		0.010		0.002		0.015	
	world	0.268	8.922			0.004		0.001	0.000		0.004		na		0.004		0.000		-0.001		0.000	
India	US	0.027	-0.127			0.059		na	0.002		na		0.016		0.002		0.007		-0.017		na	
	world	1.098	1.276			0.004		na	0.017		na		0.001		0.000		0.001		-0.001		na	
USA	US	1.016	0.610			0.143		-0.007	0.026		0.103		0.035		-0.023		-0.099		-0.017		-0.045	
	world	0.039	-2.272			0.009		0.001	0.003		0.006		0.002		-0.001		-0.006		-0.001		-0.003	
Non-ethanol producers																						
Argentina	US	na	na			0.106		na	0.002		-0.003		0.007		-0.021		-0.040		na		-0.068	
	world	na	na			0.006		na	0.015		0.000		0.001		-0.001		-0.001		na		-0.003	
Australia	US	na	na			0.021		na	0.002		0.000		0.006		0.001		na		-0.016		na	
	world	na	na			0.001		na	0.018		0.000		0.000		-0.002		na		0.000		na	
Canada	US	na	na			0.030		-0.003	na		-0.001		na		-0.005		0.003		-0.018		na	
	world	na	na			0.001		0.007	na		0.000		na		0.000		0.000		-0.001		na	
Mexico	US	na	na			0.020		na	0.008		-0.009		0.046		0.023		na		na		na	
	world	na	na			0.001		na	0.001		-0.001		0.003		0.002		na		na		na	
South Africa	US	na	na			0.048		na	0.003		-0.007		0.001		na		na		na		na	
	world	na	na			0.003		na	0.025		0.000		0.000		na		na		na		na	
World aggregate	US	0.584	0.159			0.056		0.001	0.002		-0.001		0.016		-0.001		-0.026		-0.011		-0.007	
	world	0.418	1.253			0.003		0.012	0.138		0.001		0.001		0.000		-0.001		0.000		0.000	