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

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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 (Food and Agricultural Policy Research Institute) model. The model incorporates the trade-offs 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, the European Union-25, 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 grain prices transmit worldwide. Changes in U.S. coarse grain prices also affect U.S. wheat and oilseed 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 impacts on other land uses in most countries.

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

JEL Code: Q42, Q17, Q18, Q15

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, the European Union (EU), and India.[1] 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, the EU, and India) also have expanding ethanol sectors. 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, particularly in the United States.[2] 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 prices induce land reallocation 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 by pasture use for key countries growing feedstock for ethanol (corn, sorghum, wheat,

[1] The EU refers to the EU-25.
[2] The EU, on the other hand, has an established biodiesel market.

sugarcane, and other grains) and major crops competing with feedstock for land resources such as oilseeds.

Our analysis relies extensively on the international FAPRI (Food and Agricultural Policy Research Institute) 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 second, an exogenous increase in world demand for ethanol (specifically in Brazil, China, the 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. 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 these feedstocks. 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 grain prices transmit significant shocks worldwide. Changes in U.S. coarse grain prices also affect the prices of U.S. wheat and oilseeds through land shifting away from these crops. 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 do corn and coarse grains.

In the next section, we describe our paper's place 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 our 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 in recent years. The contributions of De La Torre Ugarte et al. (2003), Elobeid and Tokgoz (2008), Elobeid et al. (2007), English, Menard, and De La Torre Ugarte (2001); English et al. (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), among 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 (sugarcane and corn). Most studies hold these constant (Gallagher et al. 2006; Koizumi and Yanagishima 2005), with the exception of that of Ferris and Joshi (2005). Recently, Elobeid and Tokgoz (2008), 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 (2008) 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.[3] The U.S. tariff insulates 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

[3] Specifically, the federal tax credit is the volumetric ethanol excise tax credit (VEETC), which is given to refiners blending ethanol with gasoline. At the time of the study, the credit was 51¢ per gallon of ethanol. It is currently 45¢ per gallon.

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 and have supported the competitiveness of cellulosic feedstock in ethanol production. However, 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 abstract away from cellulosic-ethanol expansion to reflect its lack of competitiveness based on its current cost structure and technology.[4]

The International FAPRI Model

Model structure

The international FAPRI model is a set of multi-market (multi-commodity, multi-country), non-

[4] Ethanol from cellulosic feedstock can become economically viable if it receives a significant enough subsidy to compensate for its higher cost structure relative to corn-based ethanol or if technological advancements result in lowering the cost of production.

spatial, partial-equilibrium models developed at Iowa State University.[5] 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.

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

[5] The U.S. crops, livestock, and dairy models, which are part of the FAPRI modeling system, have been developed and maintained by the University of Missouri.

coarse grains also compete for land. Sugarcane production is often on land unsuitable for other crops. However, it does compete with soybeans in Brazil and with rice in some Asian countries.

Area in the FAPRI crops model is expressed as a function of real prices, making it homogeneous of degree zero in prices by construction. Symmetry is not imposed. All analyses conducted always include an ex post check to make sure that land allocation outcomes meet land supply constraints in major countries and regions covered in the model.

We now 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 United States, 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 United States, 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. The exception is the domestic ethanol price in the United States, which is solved endogenously as long as the U.S. price remains below the Brazilian price adjusted for transportation. 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 distillers dried grains (DDG) as a major by-product. 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, but these do not threaten the protection of U.S. producers.[6] Brazilian ethanol is produced from sugarcane. Indian ethanol is produced from molasses. EU ethanol production uses a combination of grains as feedstock.

The FAPRI model is capable of handling most, but not all, important structural and regime changes. Ethanol production capacity is explicitly modeled as a function of expected net profit for both dry and wet mills separately. Utilization rates for each type of mill are modeled as a function of net profit margin. Output of ethanol is the sum of ethanol production from dry and wet mills and co-evolves with profits.[7] Demand for feedstock follows the same pattern. In the livestock industry and feed demand, we also model the dynamics of livestock and their influence on feed use and demand. However, the FAPRI model does not impose zero return in farming via exit or entry. Hence, profit margins have an important role at the margin but do not serve as a signal for exit when margins substantially deteriorate, except in the ethanol capacity equation where capacity shrinks with negative profit. The structure of the U.S. component of the ethanol sub-model is more elaborate, especially on the ethanol demand side. Because these demand characteristics have limited implication for land use, we refer interested readers to Tokgoz et al. (2007) 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

[6] The U.S. ethanol trade policy includes a 2.5% ad valorem tariff and a per unit tariff of 54¢ per gallon. However, under the Caribbean Basin Economic Recovery Act (CBERA), if ethanol is produced from at least 50% agricultural feedstock grown in a CBERA country, it is admitted into the U.S. free of duty.
[7] In each process, ethanol production is obtained by multiplying production capacity by the utilization rate.

for livestock and biofuels, and 10-year projections are generated for the period 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 parameter estimates and policy variables used in the model are available at http://www.fapri.iastate.edu/tools/. Elasticities for the ethanol sub-model are shown in Appendix Table A1.

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), 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, among others. Macroeconomic data such as gross domestic product (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

The baseline 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 and 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 soybeans in Brazil. As explained in the following sections, three important U.S. policies condition the analysis: the U.S. tariff on ethanol, the U.S. mandated use of ethanol via renewable fuel mandates, and the U.S. blender's tax credit. 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 expansion (a permanent horizontal shift of demand with respect to its baseline level) leading to an equilibrium increase in U.S. ethanol use of roughly 3%. As the U.S. demand for ethanol is very elastic at the margin, a large permanent 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 inframarginal. 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. What matters for land allocation is the change in the equilibrium value of ethanol quantity/use, which affects the derived demand for feedstock crops. The shift in demand is really the way to get to the shift in equilibrium use in a sensible way.

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 of 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 because 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(U.S. ethanol use)*) and report their values summarized in the 10-year average. The denominator of the multiplier is based on the change in ethanol use because it is the relevant change that matters for land allocation because it affects the derived demand for feedstock crops. The horizontal shift in demand is the sensible way to induce the shift in equilibrium use.

These multipliers 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, or multiplied by 100, they provide an estimate of the impact of a doubling of U.S. ethanol use on the variable of interest. 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, India, and the United States for 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 increase of ethanol demand (a permanent horizontal shift of ethanol demand in deviation from the baseline level) in Brazil, China, the EU, 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, the EU, and India)*) and again we report their values as 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, or if scaled by 100, an estimate of the impact of a doubling of ethanol use 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.

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) as they respond negatively to prices; then land devoted to coarse grains expands. Long-term land responses would be higher, as adjustment takes time.[8] 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.[9] 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 increase (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). This 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).

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[8] The FAPRI model includes lagged variables in its land supply responses, which limit the supply response to prices in the model. The long-term response with no lagged response would be characterized by higher elasticity values and larger land responses.

[9] Because of space limitations, multipliers for corn utilizations including stocks are not reported. Information can be requested from the authors.

In U.S. oilseed markets, there is a sharp reduction in land devoted to soybeans (-0.10) and, to a lesser extent, to sunflowers (-0.045). Changes in land allocations to other oilseeds exhibit smaller magnitudes in absolute value. These reductions lead to higher oilseed prices, which lead to a fall in biodiesel production (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. Although the historical pattern suggests that corn and DDG prices move in close tandem, with a much larger ethanol market projected in our study, our results show a possible departure in price movement from their historical pattern in the short run, but returning back to their strong correlation in the long run. Short-run corn and DDG price movements can diverge when the corn price is pulled up by strong ethanol demand while the supply of DDG expands substantially to depress the price in the short run. Ethanol plants usually sell a third of DDG as wet with 65% to 70% moisture content. This product is very perishable, having a shelf life of less than a week. In contrast, it takes time to build animal numbers to expand DDG demand to absorb substantial expansion in supply. Both factors can lead to a decline in the DDG price in the short run when the corn price is rising.

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 transmit to other countries, but not fully, because 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). Argentina is the second-largest exporter of corn, behind the United States. Reduction in U.S. corn exports driven by increasing corn use for ethanol gives Argentina an opportunity to expand its world market share, and hence is a strong response in the allocation for corn. Land used for corn in Egypt also expands more than the world average (0.075). Growth in land devoted to corn in Brazil and India follows the aggregate corn supply (multipliers of 0.05 and 0.059, respectively). Additional land devoted to corn in other important corn production countries, such as China, Mexico, South Africa, and Canada, is also observed (multipliers range between 0.02 and 0.048).

Higher world prices for other feed grains also occur. They translate into smaller net imports and larger net exports, but these effects are more moderate than for corn. Land devoted to feed grains other than corn 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 0.056). Sorghum area in Mexico expands above the world average level (multiplier of 0.046). 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 -0.011 or less in absolute value), except for in the EU. Sunflower land area falls in Argentina (-0.068) but increases in the EU (0.015). As the competition for land increases, there are moderate decreases in pastureland in Brazil and Argentina.

Recent U.S. ethanol policy changes provide an opportunity to illustrate the usefulness of our multipliers. The Energy Independence and Security Act (EISA) of 2007 increases the implied starch-based ethanol Renewable Fuel Standard from 7.9 billion gallons in the 2005 energy act to 15 billion gallons, an increase of nearly 90%. The U.S.-shock multipliers in Table 2, multiplied by 90, provide an estimate of the impact of the starch-based ethanol mandated expansion under the EISA relative to the 2005 mandate, assuming it is binding. For example, with such a policy shock, corn area in the United States, Argentina, and Brazil would increase by nearly 13%, 9.5%, and 4.5%, respectively. The world corn price would increase by nearly 26%. If the 2005 mandate is not binding, the ethanol shock in percent changes will be smaller than 90% moving from the current use to the new mandated use. Similarly, one could look at the removal of the U.S. blender's tax credit. The impact of the tax credit depends on the binding nature of the renewable fuel mandate. If the mandate is binding, then the tax credit is redundant and ethanol use is invariant to the credit. If the mandate is not binding, then the tax credit stimulates ethanol demand. Mapping the removal of the tax credit into a decrease in U.S. ethanol use, our multipliers can be used to predict the land allocation implications of removing the credit.

Table 3 presents multipliers for total crop area for the world and major countries. In response to a U.S. ethanol expansion, world crop area increases, with a multiplier of 0.009. Most of the increase in world crop area is through a world corn area increase. Brazil and South Africa respond the most, with multipliers of 0.031 and 0.042, respectively. Mexico follows, with a multiplier of 0.023, followed by the United States, Thailand, and Egypt.

Scenario 2 results

The shock on the world ethanol market 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 exhibits large multipliers because trade is thin: U.S. imports fall (multiplier of -2.27); Brazilian exports rise despite the exogenous increase in their demand (1.31); and the EU's imports respond sharply given the shock imposed on the EU ethanol market and the net-importing status of the region (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 the 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 feedstock in Brazil and India (sugar price multiplier of 0.13). The effect on world corn prices is a tenth of that on the sugar price (0.013) because of the limited size of 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 also has some impact on grain stocks and grain trade flows, but land area devoted to grains and grain production remains nearly unchanged in most countries. Feedstock use increases in China (0.75), the EU (0.24), India (molasses), and Brazil (sugarcane multiplier of 0.94).

In this scenario, the impact on sugarcane and sugar is the only significant change in feedstock markets. Brazilian 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). A small scale of land expansion for sugarcane is found in other major sugar-exporting countries, e.g., Australia (0.018), India (0.017), and Thailand (0.004). Worldwide, sugarcane land area increases with a multiplier of 0.138, but world sugar output falls as expected, albeit rather slightly (multiplier of -0.012). Although ethanol demand in China and the EU is also exogenously raised in this scenario, the impact on the feedstock market is obviously lower, as ethanol industries there are still in their infancy stage. Hence, changes in the area allocation of corn (primary feedstock for ethanol production in China) and wheat (major feedstock used for ethanol production in the EU) are very modest in the world. The impacts on most of the other crops and sectors are negligible.

Table 3 also presents total crop area multipliers in response to a global (non-U.S.) ethanol expansion. The world crop area multiplier is 0.001 in this scenario, which is very small relative to the multiplier for the U.S. ethanol expansion. This is also the case for most of the other countries, with the notable exception of Brazil, which has a total crop area multiplier of 0.058. South Africa, Thailand, the EU, and Egypt follow, with total crop area multipliers between 0.003 and 0.004. Since the United States is a major exporter of grains and oilseeds, any change in U.S.

corn demand impacts world markets considerably. This leads to larger land use changes in the world in response to a U.S. ethanol market expansion relative to a global (non-U.S.) shock.

Table 3 includes total crop area multipliers from Searchinger et al. (2008), a study that used the same modeling system but assumed that there was no bottleneck in the E-85 gasoline market and introduced a $10-per-barrel crude oil price shock. Searchinger et al. showed that the inclusion of indirect land use changes is crucial in estimating greenhouse gas emissions and savings from ethanol. The crop area multipliers from the Searchinger et al. study are generally larger than the crop area multipliers in this study. For example, the world crop area multiplier is 0.017 in Searchinger et al., whereas it is 0.009 in this study for the U.S. demand shock. This is because Searchinger et al. impose a long-run equilibrium assumption for the U.S. ethanol market (the U.S. ethanol industry grows until the net profit margin for the corn-based ethanol sector is exhausted to zero).

Conclusions

This study analyzes and quantifies the foreseeable emergence of biofuel markets in the U.S. and world agriculture using the international FAPRI modeling system and two ethanol demand scenarios. We examine the projected evolution of land allocation under this biofuel emergence for major feedstocks and crops, as well as for key countries. We report 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 crop prices inducing significant U.S. land allocation changes. These price effects also transmit worldwide, especially for feed grains and soybeans, 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 removing 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, rather than U.S. producers, would perceive the increased profit opportunities on the U.S. market and increase their ethanol production to meet U.S. ethanol demand.

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 a 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, mostly in Brazil.

In sum, the global effects of the biofuel expansion on land are more limited than its local effects on land and on other local industries competing for the feedstock. Effects on land reallocation within countries are sometimes large, such as in the case of 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 the 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.

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Figure 1. U.S. Ethanol Shock: Price Multipliers (Average over 2007-2017)

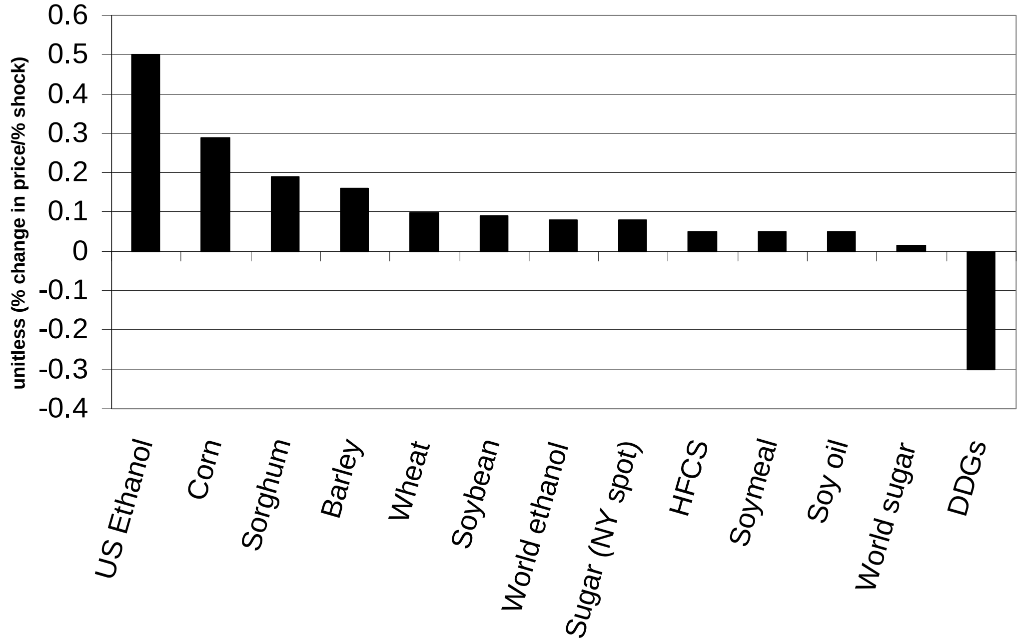

Table 1. The International FAPRI Model

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 sun-flower 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		-0.007	
	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	
Philippine	US	na	na			0.075		na	0.004		na		na		na		na		na		na	
	world	na	na			0.005		na	0.032		na		na		na		na		na		na	
Russia+Ukraine	US	na	na			0.032		0.000	na		-0.012		na		na		-0.011		-0.006		0.000	
	world	na	na			0.000		0.004	na		0.000		na		na		-0.001		0.000		0.000	
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	
Thailand	US	na	na			0.031		na	0.000		na		na		na		na		na		na	
	world	na	na			0.002		na	0.004		na		na		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	

Table 3. Impact Multipliers from Scenarios for Total Crop Area

Multipliers (unitless, 10-year average (percent change in variable /percent change in ethanol use))		
Country	**Ethanol Demand Shocks**	**Total Crop Area**[a]
Ethanol producers		
Brazil	US	0.031
	world	0.058
	Searchinger *et al*. (2008)[b]	0.052
China	US	0.008
	world	0.001
	Searchinger *et al*. (2008)[b]	0.015
EU-25	US	0.000
	world	0.003
	Searchinger *et al*. (2008)[b]	0.006
India	US	0.010
	world	0.002
	Searchinger *et al*. (2008)[b]	0.017
USA	US	0.019
	world	0.001
	Searchinger *et al*. (2008)[b]	0.026
Non-ethanol producers		
Argentina	US	-0.020
	world	0.000
	Searchinger *et al*. (2008)[b]	0.001
Australia	US	0.001
	world	-0.001
	Searchinger *et al*. (2008)[b]	0.004
Canada	US	-0.005
	world	0.000
	Searchinger *et al*. (2008)[b]	0.002
Egypt	US	0.015
	world	0.003
	Searchinger *et al*. (2008)[b]	0.021
Mexico	US	0.023
	world	0.001
	Searchinger *et al*. (2008)[b]	0.028
Russia+Ukraine	US	-0.005
	world	0.000
	Searchinger *et al*. (2008)[b]	-0.003
South Africa	US	0.042
	world	0.004
	Searchinger *et al*. (2008)[b]	0.053
Thailand	US	0.016
	world	0.003
	Searchinger *et al*. (2008)[b]	0.021
World aggregate	US	0.009
	world	0.001
	Searchinger *et al*. (2008)[b]	0.017

[a] Total crop area includes wheat, corn, sorghum, barley, soybean, rapeseed, sunflower, peanuts, sugar beet, and sugarcane.
[b] Searchinger et al. (2008) incorporates multipliers from a $10-per-barrel world crude oil price shock that increases ethanol demand and production. Multipliers are computed at the long-run equilibrium values (the U.S. ethanol industry grows until the net profit margin for corn-based ethanol sector is zero) for the scenario in which it was assumed that there was no E-85 bottleneck in the U.S. ethanol market.

APPENDIX

Table A1. International Ethanol Model Elasticities[a,b]

	Elasticities
UNITED STATES	
U.S. Ethanol Demand	
Additive Demand	
Price of ethanol/gasoline	-0.11
Voluntary E-10 Demand	
Price of ethanol/gasoline	-2.12
E-85 Demand	
Price of ethanol/gasoline	-19.45
Gasoline Consumption	
Price of gasoline	-0.06
Price of ethanol	-0.003
Per capita income	0.32
U.S. Ethanol Supply	
Wet Mill Capacity	
Profit margin (long-run)	3.41
Wet Mill Utilization Rate	
Profit margin	10.52
Dry Mill Capacity	
Profit margin (long-run)	2.23
Dry Mill Utilization Rate	
Profit margin	10.32
U.S. Ethanol Stocks	
Ethanol production	0.54
Price of ethanol	-0.48
U.S. Ethanol Trade	
Net Imports	
Ratio of domestic to world ethanol price	3.45
BRAZIL	
Brazil Ethanol Demand	
Anhydrous Ethanol Demand (mixed with gasoline)	
Price of ethanol	-0.16
Price of gasoline	-0.26
Interaction term	-0.01
Income	0.20
Population	0.13
Hydrous Ethanol Demand (competes with gasoline)	
Price of ethanol	-0.44
Price of gasoline	0.23
Interaction term	0.01
Income	0.25
Population	0.18
Brazil Ethanol Supply	
Share of sugarcane in ethanol	
Ratio of ethanol to sugar price	0.20
Brazil Ethanol Stocks	
Stocks (t-1)	0.11
Price of ethanol	-0.37

[a] Elasticities are estimated at the sample average for 2000 through 2004.
[b] All prices are in real terms.

Table A1. International Ethanol Model Elasticities[a,b] (continued)

	Elasticities
EUROPEAN UNION	
EU Ethanol Demand	
Price of ethanol	-0.18
Policy	
Trend	0.71
EU Ethanol Supply	
Production	
Price of ethanol	0.32
Policy	
Trend	0.85
Price of wheat	-0.20
Price of sugar beet	-0.12
CHINA	
Chinese Ethanol Demand	
Disappearance	
Price of ethanol	-0.26
Income	0.17
Chinese Ethanol Supply	
Production	
Lagged production	0.43
Price of ethanol	0.17
Price of corn	-0.10
INDIA	
Indian Ethanol Demand	
Disappearance	
Price of ethanol	-0.17
Income	0.25
Indian Ethanol Supply	
Production	
Lagged production	0.33
Price of ethanol	0.23
Sugarcane production	0.14

[a] Elasticities are estimated at the sample average for 2000 through 2004.
[b] All prices are in real terms.