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Bottlenecks, Drought, and Oil Price Spikes: Impact on U.S. Ethanol and Agricultural Sectors

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We project U.S. ethanol production and its impact on planted acreage, crop prices, livestock production, trade, and retail food costs. The projections are made using a multicommodity, multicountry, and a partial equilibrium model. Results indicate that expanded U.S. ethanol production will cause long-run crop prices to increase. In response to higher feed costs, livestock farmgate prices increase enough to cover the feed cost increases. If crude oil prices increase, the U.S. ethanol sector expands. Results of a 1988-type drought scenario combined with a large mandate for ethanol consumption show higher crop prices, a drop in livestock production, and higher food prices.

The recent emergence of biofuels as important agricultural commodities has generated interest in their likely impact on U.S. and world agriculture.

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Questions such as how large the ethanol and biodiesel sectors will become and how much they will affect traditional agricultural markets have increased in importance as the biofuels sector has grown. The large run-up in corn prices will have important impacts on the U.S. livestock sector, which will eventually filter down to the consumer. Recognition of these impacts has created interest in the effect of biofuels on the livestock sector and on wholesale and retail food prices.

The emergence of biofuels in the United States has been largely driven by tax incentives, federal and state mandates, and the progressive elimination of MTBE (methyl tertiary butyl ether) as an additive in many states. The 2005 Energy Policy Act, which introduced the Renewable Fuel Standard (RFS) (EIA), initiated policies targeting an increased reliance on biorenewable sources of motor fuel (gasoline and diesel). Combined with persistently high crude oil prices, the biofuels sector has taken center stage in discussions about U.S. reliance on fossil fuels and on how biofuels can help meet environmental goals.

The growing biofuels industry has led to an expanding number of studies on ethanol and other biofuel markets. Koizumi and Yanagishima were among the first to establish an international ethanol model and examine the implications of a change in the compulsory ethanol-gasoline blend ratio in Brazil on world ethanol and sugar markets. Gallagher et al. look at the competitive position of Brazilian ethanol produced from sugar processing as compared to U.S. ethanol produced from corn under the assumption of no tariffs in the ethanol market. English et al. analyze the impacts on the U.S. agricultural sector of achieving the goal of the 25 ×25 group, which is to obtain 25% of the U.S. projected energy needs from renewable energy sources in the year 2025. The renewable energy sources include ethanol from traditional crops and from cellulosic sources, biodiesel, and wind. The authors use POLYSYS (a computer simulation model of U.S. agriculture), which provides annual estimates of changes in land use resulting from the demand generated by bioenergy industries. However, their study does not incorporate impacts of the changes in the U.S. agricultural sector on international agricultural markets and the resulting adjustments on world prices since the POLYSYS model does not cover world agricultural markets.

Few papers fully endogenize the prices of feedstocks used in ethanol production, that is, sugarcane and corn. Most studies have tended to hold these constant (Gallagher et al.; Koizumi and Yanagishima). The study by Ferris and Joshi is an exception. Recent papers (Elobeid and Tokgoz; Tokgoz and Elobeid) have endogenized these prices by using a large set of multimarket agricultural models. The prices are derived through an equilibrium mechanism that equates excess supply to excess demand in each market. These studies incorporate linkages between an international ethanol model, an international sugar model, and a U.S. crops model. Contrary to Ferris and Joshi's work, which takes ethanol projections provided by the U.S. Department of Energy as given, the studies by Elobeid and Tokgoz provide projections for ethanol production and consumption in the United States based on the latest market conditions and policy settings.

The general objective of this study is to provide an estimate of how large the U.S. biofuels sector could become and to assess the likely impact of this sector on crop markets, trade, and on wholesale and retail livestock markets. Specifically, we run two scenarios that examine the impacts of a higher world crude oil price and a widespread short crop in the United States. To this end, this study uses a broad set of U.S. and international agricultural sector models, which allows the impact

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of the expansion of the ethanol sector to be captured in multiple markets. This large framework allows prices in the ethanol, crops, livestock, and dairy sectors to be endogenized, not only in the United States but also in world markets. It also captures the full response of world agricultural markets to this boom in the ethanol sector. This aspect is crucial, since the United States is a major player in world agricultural commodity markets, as a producer and a trade partner.

A baseline for U.S. and world agricultural markets is first established and then two scenario analyses are conducted. The ethanol sector has become integrated into the agricultural sector, and hence this increases the agricultural sector's susceptibility to volatility from the energy markets. Therefore, analyzing the link between the energy and the ethanol markets is vital. Thus, a scenario with higher crude oil prices but with constrained demand for ethanol is included. With the emergence of biofuels, crude oil prices have a much more direct impact on the U.S. agricultural sector compared to the prebiofuels era when it mostly affected the cost of production. The composition of the U.S. vehicle fleet affects the final impact from a change in the crude oil price. Because the ethanol sector has emerged as a viable competitor to the livestock and dairy markets for procurement of corn, it is crucial to understand the competition between these sectors. So the second scenario is a short-crop scenario that mimics the 1988 U.S. drought. This scenario is run with an ethanol mandate in place, similar to the renewable fuels standard, which places a lower boundary on the ethanol consumption in the United States.

In the following pages, we first describe the U.S. ethanol market and the components of this market that affected our modeling structure and assumptions. The methodology, which includes an explanation of the concept of long-run equilibrium, and the model calibration and data used in the study are then presented. The baseline results are outlined, followed by discussions of the two scenarios. We also present reasons why cellulosic ethanol and biodiesel production are currently not feasible in the United States. The final section presents the conclusions.

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U.S. Ethanol Sector

The U.S. ethanol industry has experienced tremendous growth over the past five years. Ethanol production has increased from less than 2 billion gallons in 2000 to nearly 5 billion gallons in 2006. Based on current construction in the industry, ethanol production capacity will more than double in the next few years. The sharp rise in ethanol production translates directly into increased use of corn for ethanol production. In 2006, 17% of the U.S. corn crop went to ethanol production. This is roughly the same amount of corn the United States exports to other countries. Only corn usage for livestock feed exceeds the corn demand from ethanol. The growth in the ethanol industry has also created a ready supply of a substitute feed for livestock from ethanol coproducts, such as distillers grains (DGs) and gluten feeds. The subsequent discussion highlights the approach used here for two major market areas, ethanol demand and the DG market.

Ethanol Demand Structure

Previous studies, such as Elobeid et al., have assumed that the U.S. ethanol industry could sell all of its production on the U.S. market at its retail energy value. Because the amount of ethanol that was projected to be produced was much greater than that needed for a nationwide E-10 blend, this meant that as much as 50% of the ethanol was projected to be consumed via E-85 blends.

For this study, a careful analysis of the number and location of existing and new flex-fuel vehicles (FFVs) was included. E-85 demand is considered to be responsive to the price of ethanol relative to its energy value. The analysis shows that the projected number of FFVs in key midwestern states (where ethanol would be the least expensive relative to gasoline) severely limits the aggregate amount of ethanol that could be consumed by U.S. FFVs.

The E-85 market faces some development issues. It will only pay for gas stations to install E-85 tanks and pumps when there are enough consumers demanding E-85 fuel for their vehicles. For consumers to purchase FFVs or convert existing cars to run on E-85, E-85 must be available from enough retail outlets and ethanol must sell at or below its energy value relative to gasoline to spur consumer demand. But if ethanol sells at such a discount, it does not pay to build new ethanol plants. We refer to this problem as the "E-85 bottleneck." The models, and the assumptions embedded in them, are constructed to account for the E-85 bottleneck.

Prior to 2009, production capacity in the model is based on industry data on plants under expansion and construction (RFA). From 2009 onward, net profit margins drive the decision of ethanol producers to expand ethanol production capacity. Thus, the model mimics the decision faced by investors who are considering investment in new ethanol facilities during the projection period.

Distillers Grains Market

The expansion of the U.S. ethanol sector has affected the U.S. livestock and dairy sectors in two dimensions. The first is through the competition for corn as feedstock, by increasing the price of corn and diverting corn away from the livestock and dairy sectors. The second is through the production of coproducts, DGs, and gluten feed that can be substituted for corn and soybean meal in livestock feed rations. In this study, the DG market is modeled in detail, incorporating rations of ruminant animals. DGs primarily replace corn with modest impacts on soybean meal requirements. With a large U.S. and international market for DGs in ruminant feed, the DG price reflects its feed value in ruminant rations as a replacement for corn. This means that DG prices will track corn prices.

The inclusion of DGs in the model produces some profound effects. For example, Elobeid et al. assume that the impact of higher feed costs would be lower for beef producers than for hog and poultry producers because DGs can more readily be included in ruminant rations than in hog and poultry rations. Instead, because DG prices track corn prices, the impact on cattle feed is as great as the impact on hog feed. With more expensive DGs, world poultry and swine producers continue to purchase corn and soybean meal and thus soybean prices increase rather than decrease. This increase in soybean prices causes South American soybean acres to increase substantially as the United States reduces its soybean production.

Methodology

Defining Long-Run Equilibrium

One of the contributions of this study to the ethanol literature is to capture in the models the impact of entry and exit behavior of economic agents in ethanol

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production. The study utilizes long-run equilibrium conditions to help us understand the eventual impact of the biofuels sector on agriculture. When a market is at a long-run equilibrium, no group of producers has an incentive to change its behavior. For example, if the ethanol industry is in equilibrium, then there is no incentive to build new ethanol plants and there is no incentive to shut down existing plants. In this study, capacity of the ethanol sector depends on the net profit margins for ethanol plants. Expansion comes to a halt when the net profit margins reach zero.

The same concept is applied to the U.S. livestock and dairy sectors. In response to increased demand for corn by the ethanol sector, feed prices increase. The models are constrained so that the increased costs will lead to a reduction in supply and subsequent output price increases that return net profits to normal levels that are just sufficient to keep livestock and dairy producers in business. This constraint was imposed on the baseline projections as well as on our analysis of the higher crude oil scenario. The model results that fully reflect these adjustments are referred to as the "long-run equilibrium," which is achieved in the last year of the baseline and scenario projections.

Price transmission of higher feed costs to other countries is imposed. However, full feed price transmission is not imposed in countries where trade barriers exist. The effect of this assumption is that the United States does not lose a significant amount of competitive advantage in international meat markets when U.S. corn and soybean meal prices increase. High U.S. feed prices cause high international feed prices, and the U.S. meat industry continues to have a cost advantage in meat production. Without this assumption, most of the adjustment of the livestock sector would be achieved through dramatic reductions in U.S. net exports, a result that assumes that the rest of the world somehow gains a competitive edge over U.S. livestock producers.

Model Calibration and Data

Broad models of the world agricultural economy are employed in this study to evaluate the likely impact of biofuels growth on agricultural markets.[1] The structure used is a modeling system that contains models of supply and demand for important temperate agricultural products in all major producing and consuming countries in these markets. The underlying modeling approach relies and expands upon a recently created biofuels model that extends an already established multimarket model of world agriculture and food markets.

The individual agricultural sector models used are partial equilibrium, econometric, nonspatial policy models. That is, all other sectors of the economy outside of the relevant commodities are considered as given. Parameters in the model are directly estimated, surveyed from the literature, or obtained from consensus of expert opinion. Country sources and destinations of trade are not monitored. The models strive to capture policy instruments that influence the incentives faced by economic agents. This includes domestic policies (for example, price support) and border policies (e.g., duties, tariff rate quotas, export subsidies). Other policies that are difficult to represent quantitatively, such as environmental regulations, are accounted for exogenously.

In general, data for supply and utilization of agricultural commodities were obtained from the F.O. Lichts Online Database; the Food and Agricultural

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Organization (FAO) of the United Nations (FAOSTAT Online); and the Production, Supply and Distribution View (PS&D) of the U.S. Department of Agriculture (USDA). Macroeconomic data were gathered from various sources, including the International Monetary Fund and Global Insight.

The baseline is set up using U.S. and international commodity models calibrated on 2006 historical data (2006–7 marketing year data for crops models). The projections cover the period between 2007 and 2016 (2007–8 and 2016–17 marketing year). The two scenarios are then analyzed relative to these baseline projections. The first scenario is a higher crude oil price scenario with an assumption of bottleneck in the U.S. ethanol demand. The second one is a drought scenario in the U.S. crops sector, with an ethanol mandate imposed on ethanol consumption.

For any crude oil price, we calculate the price of unleaded gasoline through a price transmission mechanism. This price impacts ethanol demand and, together with the capacity of the ethanol industry, determines the price of ethanol (fully adjusted for the $0.51-per-gallon tax credit that gasoline blenders receive) and the incentive to invest in additional ethanol production capacity. Ethanol production determines the demand for corn. Investment in new ethanol plants will take place if the market price of corn allows a prospective plant to cover all the costs of owning and operating an ethanol plant. Long-run equilibrium prices for ethanol, crops, and livestock are achieved when there is no incentive to construct new plants, no incentive to expand or contract livestock and dairy production, and all crop markets clear.

For the baseline and the scenarios, crop price increases caused by expansion of ethanol production are sustained throughout the projection period. Thus, the livestock industry is assumed to adjust production levels to maintain profitability. Crop price increases caused by a short crop are temporary so that the livestock industry only makes short-run production adjustments as needed. Thus, the livestock price increases caused by a temporary shock will be lower than those caused by a permanent shock will.

The relative profitability of producing ethanol from corn, corn stover, and switchgrass grown in the Corn Belt was examined. Because ethanol from corn is the only one of these three sources to generate positive returns given current production cost estimates, it is the only one that we include in our baseline and scenarios. This is not to say that other sources of ethanol from cellulose may not prove cost-effective in the future.

Baseline Projections

Energy Markets in the Baseline

The modeling system used relies on U.S. refiners' acquisition cost of crude oil. This price is typically lower than the U.S. light sweet crude price that is traded on futures markets (NYMEX). The price difference between the two price series has averaged approximately $6.75 per barrel.[2] We subtract $6.75 from NYMEX crude oil price futures to obtain the crude oil price projections for this analysis. This basis results from the lower quality of crude typically imported into the Gulf of Mexico and transportation costs. At the time of modeling, futures prices were available through December 2012. To extend the price series to 2016, the end

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of the projection period, crude oil price changes are calculated from projections provided by Global Insight and then applied to the futures price series.

The ethanol price is solved in the model after taking into account the amount of ethanol that is produced and consumed. The ethanol price data include the $0.51-per-gallon blender's credit. In the baseline, the projected expansion in ethanol production drives down ethanol prices below the price of gasoline, where they remain throughout the projection period. The reason why ethanol prices fall significantly below the price of gasoline is that we assume that consumers are rational and realize that ethanol has lower energy value than gasoline so that an E-10 blend will have to sell for less than gasoline at increased production levels. Thus, the price of ethanol must fall so that blenders will choose to include it in their blends and consumers will choose to use the blended fuels.

By the end of the projection period, the wholesale price of ethanol is $1.58 per gallon (table 1). When we subtract the blender's credit, the effective price for the blenders is $1.07 per gallon. The end-of-period wholesale price of gasoline is $1.80 per gallon. This means that ethanol is selling at about $0.13 per gallon below its energy value of $1.20 per gallon. These results indicate that ethanol demand becomes the limiting factor to the growth of the ethanol sector. As production increases, the price of ethanol has to fall relative to its energy value to entice gas stations and consumers to purchase the product.

In terms of profit margins for the ethanol plants, in the baseline the plants cover their variable costs, but they do not cover their full costs for most of the period. We assume that the long-run equilibrium is achieved in 2016, such that investors are indifferent between building and not building a new ethanol plant. This indifference occurs because the ethanol industry stops growing in response to earlier negative earnings. Higher corn yields eventually allow the price of corn to fall so that this equilibrium condition is achieved.

Corn and Soybean Markets in the Baseline

As mentioned earlier, ethanol production continues to grow until the plants that are currently under production have come online in early 2009. Then, the capacity growth dramatically slows as ethanol prices fall below their energy value. At this point, the size of the ethanol industry is slightly less than 14 billion gallons and the annual corn grind is slightly in excess of 5 billion bushels. This relatively large quantity of corn for ethanol is obtained by shifting U.S. crop acreage from other crops to corn and by reducing U.S. corn exports and corn fed to livestock. The drop in U.S. soybean production is offset by increased South American production. As corn yields grow toward the end of the projection period, markets are eventually able to adjust to this corn grind, and market prices begin to revert to more normal levels.

Distillers Grains in the Baseline

As it became clear that the ethanol industry was experiencing a period of rapid growth that would in turn provide a large supply of DGs, it also became clear that livestock feeders would find a way to incorporate this product into their feed rations. The results indicate that U.S. and world ruminant demand is strong

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Table 1. Impact of high crude oil prices and drought on U.S. ethanol sector

		Baseline 2016	Oil + $10, with E-85 Bottleneck	Percent Chg w/Bottleneck	Baseline 2012	Drought with Mandate	Percent Chg Drought
Ethanol							
Production	(Million gallons)	14,807	22,893	54.6%	15,020	14,676	−2.3%
From corn	(Million gallons)	14,446	22,359	54.8%	14,654	14,304	−2.4%
Net imports (Ethyl alcohol)	(Million gallons)	315	313	−0.6%	294	304	3.3%
Disappearance	(Million gallons)	15,122	23,168	53.2%	15,311	14,985	−2.1%
Ending stocks	(Million gallons)	939	1,347	43.5%	940	933	−0.8%
Ethanol, FOB Omaha	(Dollars/gallon)	1.58	1.75	11.2%	1.64	1.72	5.2%
Distillers Grains							
Production (dry equivalent)	(Thousand tons)	39,929	67,004	67.8%	40,759	40,637	−0.3%
Domestic use	(Thousand tons)	37,491	61,304	63.5%	38,782	39,096	0.8%
Net exports	(Thousand tons)	2,439	5,700	133.7%	1,977	1,541	−22.0%
Price, Lawrenceburg, IN	(U.S. dollars/ton)	105.49	122.92	16.5%	105.75	148.62	40.5%

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enough to cause the prices of DGs to track corn prices. This means that the cost of rations that contain DGs instead of corn increase by almost as much as rations that contain no DGs. In other words, the presence of large quantities of DGs does not confer any particular benefit to any species. Faced with high DG prices, nonruminant rations eventually revert to a corn and soybean meal diet, and this helps maintain price strength in the soybean market.

The baseline projections show that the U.S. beef sector is by far the dominant user of DGs. This result implicitly assumes that the DG product will be transported from DG surplus areas in the Corn Belt to cattle feeding states such as Oklahoma and Texas. The model assumes a maximum inclusion rate in pork and poultry rations of 20% in 2007. For poultry the maximum inclusion rate rises to 25% over time. Projected DG consumption never comes close to these maximum inclusion rates and in fact falls off dramatically in the outer years. One key assumption made was that changes in feed rations do not affect meat quality if actual inclusion rates are less than maximum inclusion rates. If meat quality suffers then the demand for DGs from cattle feeders would be lower than that assumed here. Lower demand translates into a lower price and subsequently lower margins for ethanol plants and a lower break-even price of corn. This lower corn price would then reduce corn acreage.

In the baseline, DG prices lag behind corn prices in 2007 but they catch up in later years. For every 17 pounds of DGs that must be sold on the market, about 56 pounds of corn must be taken off the market to produce the ethanol. The ruminant animals that would have consumed these 56 pounds of corn utilize the DG coproduct instead. It would take a major price reduction to make it worthwhile to utilize this product in nonruminant rations, and this price discount does not occur. The availability of DG supplies also opens up the possibility of DG exports, and the results indicate DG trade will develop.

Scenarios and Results

The results of the two scenarios are presented relative to the baseline projections. The first scenario, which is an increase in the crude oil prices by $10 per barrel throughout the projection period, assumes that a bottleneck exists in the ethanol sector. This means that there are not enough FFVs to absorb the additional ethanol resulting from the ethanol expansion generated by the higher crude oil price. In the second scenario, which is the short-crop or drought scenario, yield patterns from the 1988 drought are used to reduce yields in barley, corn, soybeans, and wheat in the 2012–13 marketing year. This shock is introduced in the middle of the projection period to allow models to react to the shock and return to normal levels before the projection period ends. The scenario also includes a high ethanol mandate. Table 1 compares the long-run equilibrium results for the baseline and the two scenarios for U.S. crops and livestock for major variables.[3]

Higher Crude Oil Price Scenario

In the first scenario, an increase in the price of crude oil by $10 per barrel results in a 55% increase in ethanol production in 2016–17, which is defined as the long-run equilibrium in supply (table 1).[4] Ethanol produced from corn increases from

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14.4 billion gallons in the baseline to 22.4 billion gallons. The corn grind for ethanol in the baseline scenario is approximately 5 billion bushels, which increases to 8.2 billion bushels under higher oil prices. The corn price increases by 20%, from $3.15 per bushel in the baseline to $3.78 per bushel in the scenario. U.S. corn, soybean, and wheat exports decline between 12% and 30% (table 2).

Results for all the livestock species follow a similar pattern. Both feed prices and livestock farm-gate prices increase dramatically. For example, an increase in the corn price from $3.16 to $3.78 and a 5% increase in the soybean meal price result in a 13.4% increase in the feed cost of producing pork and a 6.7% increase in live hog prices. This relatively large live hog price change leads to a relatively small increase of 1.5% in retail pork prices (table 3). In terms of the retail prices, we assume that per-unit feed cost increases are passed through the meat supply chain. Thus, as the ratio of feed cost to total value at each point in the supply chain decreases, so does the percent change in meat retail prices.

Per capita pork consumption falls by 0.6% and pork exports fall by 6.2%. Total pork production falls by 1.5%. The impact on the retail price is small because none of the other costs associated with processing, transporting, and retailing pork is impacted by ethanol. Per capita pork consumption does not respond very strongly to a retail price increase because the prices of all livestock products increase by similar amounts at the same time. Pork exports fall because worldwide pork consumption falls slightly in response to higher pork prices and because the United States loses a small part of its competitive position relative to the European Union.

Exports of pork, broilers, and turkeys decline, but by a smaller percentage than crop exports do. The reason for this difference is that world demand for U.S. meat is largely unaffected by higher feed-grain prices because the rest of the world's livestock producers also face higher feed prices. Total world meat consumption declines because of higher prices, but U.S. producers still would find it profitable to supply world markets. The same situation applies to nonfat dry milk, which is the main dairy product that the United States exports. Beef exports are projected to increase because the price of beef relative to other meats declines.

Our results also provide projections for the biodiesel sector. These results are not nearly as significant as for the ethanol sector. When crude oil prices increase, the price of biodiesel also increases. However, an increase in crude oil prices dramatically increases corn acres in the long run. The resulting reduction in soybean acres drives up soybean oil prices and, by extension, the prices of other oils and fats. This increase in soybean oil prices dampens the incentive to expand the biodiesel sector.

Impact on Food Prices

The food price impacts from additional growth in the ethanol industry are relatively small, about 1%. While the meat and dairy sectors see price increases between 1% and 3%, the cereals and bakery sector experiences less than a 1% increase in price. These impacts follow from the farmgate value embedded in retail prices for food. Between 20% and 50% of the retail price for meat and dairy products flows back to the farm. Thus, the impact of higher feed costs on the farm can be seen in retail prices. For many cereal and bakery items, such as bread or

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Table 2. Impact of high crude oil prices and drought on U.S. crops

		Baseline 2016	Oil + $10, with E-85 Bottleneck	Percent Chg w/Bottleneck	Baseline 2012	Drought with Mandate	Percent Chg Drought
Corn							
Planted area	(Million acres)	92.4	102.9	11.4%	93.6	95.9	2.4%
Production	(Million bushels)	14,733	16,386	11.2%	14,143	10,947	−22.6%
Exports	(Million bushels)	2,458	1,715	−30.2%	1,975	763	−61.4%
Feed use	(Million bushels)	5,748	5,058	−12.0%	5,536	4,649	−16.0%
Fuel alcohol use	(Million bushels)	5,013	8,228	64.1%	5,170	4,786	−7.4%
Farm price	(U.S. dollars/bushel)	3.15	3.78	20.0%	3.31	4.76	43.8%
Wheat							
Planted area	(Million acres)	57.0	53.4	−6.3%	57.5	57.5	0.0%
Production	(illion bushels)	2,181	1,996	−8.5%	2,139	1,899	−11.2%
Exports	(Million bushels)	1,038	824	−20.6%	964	738	−23.4%
Domestic feed	(Million bushels)	189	232	22.9%	242	366	51.2%
Farm price	(U.S. dollars/bushel)	4.29	4.68	9.1%	4.29	4.93	14.9%
Soybeans							
Planted area	(Million acres)	68.5	64.4	−6.0%	68.6	66.4	−3.2%
Production	(Million bushels)	3,051	2,851	−6.6%	2,929	2,321	−20.7%
Exports	(Million bushels)	882	772	−12.5%	938	620	−33.9%
Domestic use	(Million bushels)	2,166	2,078	−4.1%	1,991	1,754	−11.9%
Farm price	(U.S. dollars/bushel)	6.56	7.15	9.0%	6.97	8.52	22.2%
Soybean meal							
Production	(Thousand tons)	47,334	45,595	−3.7%	43,469	38,451	−11.5%
Exports	(Thousand tons)	8,672	9,312	7.4%	7,988	2,995	−62.5%
Domestic use	(Thousand tons)	38,824	36,446	−6.1%	35,645	35,650	0.0%
48% Meal price	(U.S. dollars/ton)	158.58	166.14	4.8%	178.98	230.20	28.6%

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Table 3. Impact of high crude oil prices and drought on U.S. livestock sector

		Baseline 2016	Oil + $10, with E-85 Bottleneck	Percent Chg w/Bottleneck	Baseline 2013	Drought with Mandate	Percent Chg Drought
Beef							
Imports	(Million pounds)	3,858	4,058	5.2%	3,655	3,786	3.6%
Production	(Million pounds)	28,295	27,884	−1.5%	28,313	27,618	−2.5%
Domestic use	(Million pounds)	29,896	29,625	−0.9%	29,742	29,186	−1.9%
Exports	(Million pounds)	2,249	2,339	4.0%	2,233	2,255	1.0%
Beef retail price	(U.S. dollars/pound)	4.52	4.62	2.1%	4.34	4.51	3.9%
Pork							
Imports	(Million pounds)	1,160	1,129	−2.7%	1,109	1,049	−5.4%
Production	(illion pounds)	22,920	22,569	−1.5%	22,443	22,318	−0.6%
Domestic use	(Million pounds)	19,938	19,816	−0.6%	19,716	19,569	−0.8%
Exports	(Million pounds)	4,140	3,883	−6.2%	3,822	3,791	−0.8%
Pork retail price	(U.S. dollars/pound)	3.30	3.35	1.5%	3.12	3.19	2.1%
Broiler							
Production	(Million pounds)	40,944	40,274	−1.6%	38,617	37,571	−2.7%
Imports	(Million pounds)	66	66	0.0%	60	60	0.0%
Exports	(Million pounds)	6,828	6,723	−1.5%	6,195	5,968	−3.7%
Domestic use	(Million pounds)	34,170	33,609	−1.6%	32,477	31,687	−2.4%
Broiler retail price	(Cents/pound)	196.01	199.99	2.0%	188.68	194.04	2.8%
Turkey							
Production	(Million pounds)	6,275	6,204	−1.1%	6,068	5,985	−1.4%
Imports	(Million pounds)	21	21	0.0%	18	18	0.0%
Exports	(million pounds)	738	722	−2.2%	670	645	−3.7%
Domestic use	(Million pounds)	5,554	5,503	−0.9%	5,412	5,359	−1.0%
Turkey retail	(U.S. cents/pound)	126.26	129.93	2.9%	123.17	127.59	3.6%
Eggs							
Production	(Million dozen)	8,257	8,209	−0.6%	8,016	7,937	−1.0%
Exports	(Million dozen)	222	222	0.0%	215	215	0.0%
Disappearance shell egg	(Million dozen)	4,878	4,850	−0.6%	4,734	4,686	−1.0%
Shell egg retail price	(U.S. cents/dozen)	162.96	168.06	3.1%	158.69	167.43	5.5%

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Table 3. Continued

		Baseline 2016	Oil + $10, with E-85 Bottleneck	Percent Chg w/Bottleneck	Baseline 2013	Drought with Mandate	Percent Chg Drought
Dairy							
Milk Production	(Million pounds)	204,112	203,483	−0.3%	197,000	196,058	−0.5%
Butter							
Production	(Million pounds)	1,417	1,410	−0.5%	1,445	1,433	−0.8%
Imports	(Million pounds)	61	61	0.0%	52	52	0.0%
Domestic use	(Million pounds)	1,468	1,461	−0.5%	1,484	1,474	−0.7%
American Cheese							
Production	(Million pounds)	4,469	4,455	−0.3%	4,309	4,288	−0.5%
Imports	(Million pounds)	40	40	0.0%	40	40	0.0%
Domestic use	(Million pounds)	4,471	4,458	−0.3%	4,310	4,292	−0.4%
Other Cheese							
Production	(Million pounds)	6,874	6,859	−0.2%	6,458	6,436	−0.3%
Imports	(Million pounds)	438	438	0.0%	426	426	0.0%
Domestic use	(Million pounds)	7,137	7,122	−0.2%	6,707	6,686	−0.3%
Nonfat Dry Milk							
Production	(Million pounds)	2,037	2,014	−1.1%	1,847	1,814	−1.8%
Exports	(Million pounds)	873	853	−2.3%	765	738	−3.6%
Domestic use	(Million pounds)	1,165	1,163	−0.2%	1,083	1,079	−0.4%
Evap. and Condensed Milk							
Production	(Million pounds)	633	632	−0.2%	640	637	−0.4%
Exports	(Million pounds)	71	71	0.0%	71	71	0.0%
Domestic use	(Million pounds)	573	572	−0.2%	579	577	−0.4%
Wholesale Prices							
Butter, CME	(Cents/pound)	139.6	148.0	6.0%	138.3	149.6	8.2%
Cheese, Am., 40, CME	(Cents/pound)	140.9	143.3	1.7%	140.0	143.3	2.3%
Nonfat dry milk, AA	(Cents/pound)	111.1	111.8	0.6%	111.8	113.0	1.1%
Evaporated	(Cents/pound)	162.3	162.8	0.3%	159.8	160.6	0.5%
Retail Prices							
Butter, salted, AA, stick	(Dollars/pound)	3.54	3.64	2.7%	3.41	3.54	3.8%
Cheese, natural cheddar	(Dollars/pound)	5.22	5.28	1.0%	5.05	5.13	1.4%
Milk, fresh, whole fortified	(Dollars/pound)	3.33	3.38	1.2%	3.32	3.38	1.7%

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corn flakes, much less than 10% of the retail price flows back to the farm. So farm price changes have smaller effects on cereal and bakery retail prices.

This study evaluates the impacts of ethanol on food prices only from the direct effects of higher feed costs on livestock. We do not measure food price increases from high fructose corn sweeteners or the effects on fruit and vegetable supplies from increased competition for land from corn. In addition, food price increases are assumed to be set in perfectly competitive markets. This assumption implies that higher feed prices travel through supply chains in fixed dollar amounts. If, instead, higher feed prices move through in fixed percentage terms, then food price increases would be greater than reported here.

Because world feed prices track U.S. feed prices, the rest of the world's consumers would also see higher food prices. To the extent that both feed and livestock markets are closely integrated in all countries, the food price increases reported for the U.S. consumer would also be felt by the rest of the world. However, consumers in the rest of the world tend to spend a lower proportion of their food dollar on meat and dairy products relative to the U.S. consumer. Hence, the impact of the increase in meat and dairy prices would tend to be less in these countries. However, a higher proportion of income, especially in developing countries, is spent on food so that higher food prices will tend to affect these consumers more. In addition, many countries do not have free trade in either meat or feed grains, so trade barriers would need to be accounted for to obtain a good estimate of the impact of U.S. ethanol on world food prices.

Short Crop with Ethanol Mandate Scenario

A major concern of livestock feeders is that they will not be able to compete with ethanol producers in a short-crop year caused by, for example, a widespread drought in the Corn Belt. With a large ethanol industry competing with livestock producers for corn, there is no doubt that corn prices would increase significantly in a short-crop year. Economic theory and historical events in 1995 suggest that corn prices would rise until operating margins of ethanol plants turn negative, at which point plants would begin to shut down, thereby increasing the supply of corn available to livestock feeders.

In this scenario, there is a short crop occurring in 2012–13, with ethanol plants operating under a mandate of 14.7 billion gallons. Given the mandate, any required adjustment in demand would occur outside the ethanol industry, which would continue to operate, covering the increased cost of corn by passing on higher ethanol prices to blenders. U.S. regional yields of barley, corn, soybeans, and wheat in 2012–13 were changed from their trend levels by the same percentages that yields were observed to have changed from trend levels in 1988. The year 1988 represents the most recent year of major drought in the U.S. Corn Belt. Barley yields decrease by 29%, corn yields decline by about 25%, while soybean yields fall by about 18%, and wheat yields fall by 11%.

The short crop causes corn and soybean prices to spike in the 2012–13 marketing year. Corn prices rise 43.8% above baseline levels. Soybean prices rise by 22.2% (table 2). Corn exports and stock levels both decrease by more than 60% in response to a short crop. The large reduction in exports results from ethanol producers and domestic livestock producers winning the competition with foreign buyers for

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U.S. corn. Corn exports from South America, China, and other countries increase to fill part of the decline in U.S. corn exports. The amount of corn fed to U.S. livestock declines by 16% (887 million bushels). This reduction is partly accounted for by a drop in production and partly by an increase in the amount of wheat, DGs, sorghum, and oats that is fed.

Ethanol trade increases moderately as the imported ethanol price inclusive of the tariff and transportation cost remains higher than the U.S. price (table 1). Under free ethanol trade, ethanol imports could play a bigger role in attenuating the negative impact of short crops under an ethanol mandate as blenders could source the ethanol more cheaply abroad. Most of the adjustments to the drought occur in the year of the drought and the following year. In the long run, the sectors return to baseline levels.

Production levels for the livestock sector adjust in the 2013 calendar year because of higher feed costs. Broiler production decreases the most, by about 2.66%, with milk production adjusting the least, by 0.5% (table 3). The amount of adjustment differs across these livestock products because of differences in feed rations, reliance on exports, and the degree of competition each product faces. Wholesale egg prices are projected to increase the most, by 11.5%, followed by wholesale broiler prices, by about 10%. Prices and production levels are not affected by a greater amount in this scenario, because livestock producers are assumed to view the production shock as being temporary. Thus, they do not adjust herd size as much as they would adjust to a permanent shock in feed prices.

Lack of Cellulosic Ethanol in the Scenarios

Cellulosic ethanol is not considered in this study. We assume that individuals are self-interested and therefore will not invest unless there is an expectation of making a positive return. We examine two forms of cellulosic ethanol that would rely on feedstock from the Corn Belt, namely, corn stover and switchgrass. We find that neither would be economically justifiable, even at the higher crude oil and corn prices in the higher crude oil price scenario.[5]

Economic Feasibility of Stover-Based Ethanol

The National Renewable Energy Laboratory (NREL) provides detailed production cost estimates for corn-stover-based ethanol (Aden et al.). We use the NREL estimates for a plant that uses 2,000 tons of corn stover per day and produces 51 million gallons of ethanol per year. This plant has a 50-mile-radius draw area for corn stover. We assume that the plant offers a plant-gate price that attracts corn stover from the edge of this draw area.

In deviation from the NREL study, we compile different corn stover collection costs that are provided by Iowa State University Extension for 1,265 pound bales as follows: baling, \$10.10; staging, \$2.25; and hauling, \$15.00 (\$0.30 per mile for 50 miles).[6] We exclude chopping charges of \$8.00 per acre or \$2.00 per bale because it is uncertain as to what form the plant would prefer to receive the bales. In addition, we use the NREL estimates of the required premium to farmers of \$5.50 per bale and a lost fertilizer value of \$4.00 per bale. The total cost per delivered dry ton is \$73.70. With an assumed conversion of 70 gallons per ton, the raw material

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Table 4. Costs of corn stover versus corn for ethanol

	(Dollars per gallon of ethanol)	
	Corn Stover	Corn
Raw material costs	1.1	1.2
Capital costs	0.6	0.2
Operating costs	0.4	0.5
Total	2.0	1.9

cost is $1.05 per gallon. We then use the capital cost of $197.4 million from the NREL report amortized over ten years at 10% interest with annual payments of $31.3 million to get a capital charge per gallon of $0.61. We use the variable costs of $0.36 per gallon from the NREL report.

Table 4 compares the costs of stover to those for a corn-based ethanol plant for a year in which corn is worth $4.50 per bushel delivered to the plant. We assume that the corn-based ethanol plant could sell DGs at $150 per ton and use the assumptions from the Elobeid et al. study for the fixed and variable costs for the corn-based ethanol plant.

This analysis shows that it does not pay to produce ethanol with corn stover when corn is $4.50 per bushel. In fact, only at a corn price of $4.80 per bushel is the investor indifferent between a cellulosic ethanol plant and a corn-based ethanol plant. This breakeven price would increase if we add the costs associated with chopping straw or wrapping bales. It would fall if the investors were willing to accept a lower rate of return or if a longer plant life were projected.

Economic Feasibility of Switchgrass-Based Ethanol

In addition to some of the disadvantages associated with baling and moving corn stover, switchgrass in the Corn Belt must also compete against corn and soybeans for land. Farmers will not be willing to plant switchgrass unless it offers a net return comparable to that of corn. Babcock et al. calculated the price at which farmers would consider changing to switchgrass as $110.00 per ton of switchgrass from land with a yield of 4 tons per acre and $82.00 per ton for land with a yield of 6 tons per acre. The maximum that ethanol plants can bid for the same tons is about $37.00 per ton in years when ethanol is selling for $1.75 per gallon. Under these conditions, switchgrass simply cannot offer farmers a market incentive that offsets the advantages of growing corn.

A key insight is that there is no ethanol price that makes it worthwhile to grow switchgrass because any ethanol price that allows ethanol plants to pay more for switchgrass also allows them to pay more for corn. As long as farms are responding to net returns in a rational manner and as long as ethanol plants are paying their breakeven price for raw material, farmers will plant corn as an energy crop. Switchgrass in the Corn Belt will make economic sense only if it receives an additional subsidy that is not provided for corn-based ethanol.

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The same logic that works against switchgrass also works against biodiesel. The main crop for U.S. production of biodiesel is soybeans. Soybeans produce fewer bushels per acre and less energy value per bushel than corn, so as long as market forces are working, and in equilibrium, producers targeting energy crops would choose corn over soybeans.

Conclusions

Over the last year, the U.S. agricultural sector has undergone significant changes in response to higher energy prices and the accompanying ethanol and biodiesel booms. Both corn acreage and prices have risen dramatically since mid 2006. The ripple effect of these shifts is still flowing through the rest of the sector. This study examines the long-run prospects for biofuel development and the effects on agriculture using a multicommodity, multimarket set of models, incorporating both U.S. and world agricultural responses to the growth in biofuels. Baseline results show continued growth in biofuels, mainly dominated by U.S. ethanol. The baseline projections show the U.S. ethanol industry doubling in size within the next ten years. Corn prices are projected to remain above $3 per bushel and corn planted acreage is projected to remain above 90 million acres.

Two scenarios are examined to show the responsiveness of the biofuel and agricultural sectors to exogenous events. The first scenario looks at the impact of higher crude oil prices. The higher oil prices raise the net returns to ethanol production and promote additional growth in the ethanol industry. Long-run ethanol production increases by 55% over baseline projections. The ethanol expansion increases demand for corn, and corn acreage is projected to increase by 11% to over 100 million acres. Soybean and wheat areas decline by 6% each to offset some of the corn acreage gains. Corn prices under the scenario are 20% higher than baseline levels, increasing feed costs and leading to a reduction in meat production of 1% to 2%.

The second scenario examines the impact of a 1988-style drought under a renewable fuels mandate. The drought was placed in the middle of the projection period. With corn, wheat, and soybean production off by between 11% and 23%, prices rise by 44% for corn, 15% for wheat, and 22% for soybeans. In all three markets, U.S. exports drop significantly, with domestic uses falling less drastically. For corn, both ethanol and feed use are reduced from baseline levels. However, the renewable fuels mandate prevents ethanol production from dropping substantially. Livestock production is impacted, with broilers and beef having the largest declines. The U.S. crop shortage provides a temporary opening for U.S. trade competitors, especially in the grain and oilseed markets.

One of the main differences between the two scenarios is due to the persistence of the shock to the biofuel and agricultural sectors. In the crude oil price shock scenario, the change in crude oil price is permanent, whereas the short-crop scenario is a temporary one-time shock to crop yields. This impacts the response of the ethanol sector, as well as those of the livestock and crop sectors.

The results from the baseline and the two scenarios show that biofuels will continue to impact the agricultural sector for years to come, and these impacts will be felt throughout the world. As researchers and entrepreneurs around the world push for new breakthroughs in biofuel and coproduct production and

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usage, it is likely that some of the assumptions made in this analysis will no longer be pertinent. The outlook provided here depends on several assumptions. These include the outlook for cellulosic ethanol development, the ability of livestock to adapt to the use of biofuel coproducts in feed rations, the possible feedback of ethanol production on gasoline prices and supplies, the ability of the U.S. ethanol industry to move through supply and demand bottlenecks, and the crude oil prices. At the time we began our analyses, crude oil prices, both nearby and further out, were in the $60 per barrel range. So the $10 per barrel shock represented a sizable price shock of over 15%. Although, the crude oil market has moved strongly upward since then, the $10 per barrel shock still shows a compelling story. Our results indicate that this size of a crude oil price shock would greatly increase ethanol production and corn prices even with an ethanol demand bottleneck. The Energy Independence and Security Act that was signed in December of 2007, after the analyses in this study were completed, would also impact our results. The mandates in that Act require 15 billion gallons of corn-based ethanol and 16 billion gallons of cellulosic ethanol. These mandates will likely put more upward pressure on cropland prices and crop production costs than our study indicates.

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Endnotes

[1]Because a large set of multicountry, multicommodity models are used, detailed description of these models and elasticity values are available from the authors upon request.

[2]The average price difference depends on the time period used. Looking back to the beginning of 2003, the average price difference was lower, at approximately $5.00 per barrel.

[3]Detailed results for each scenario, each year, and for other countries are available from the authors.

[4]The year 2016/17 is the last year of the projection period, which is also the year in which long-run equilibrium conditions hold for all relevant sectors.

[5]We do not analyze the viability of cellulosic feedstocks from other regions, such as wood chips from the Southeast.

[6]The Aden et al. report calculates total costs associated with the baling and transportation of corn stover at $62 per dry metric ton or $31 for a 1,265-pound bale of 15% moisture stover. The authors assume that this cost will be reduced to $33 per dry metric ton in the future through "improved collection." However, we do not expect costs to fall dramatically since we believe that farmers and agricultural equipment manufacturers have already squeezed costs from this system.

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