US Biofuels Analysis Under Uncertainty and Volatility in the Biofuels Industry: FAPRI Stochastic Modeling

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Abstract

Stronger demand for corn to produce ethanol has translated into higher prices for it and other cereals in world commodity markets. Likewise, increased demand for vegetable oil used to convert to biodiesel (especially in the EU) will result in higher vegetable oil prices and increased supplies of oilseed meal. It is clear that increased biofuel production derived from agricultural commodities has far reaching implications that span a variety of commodities. Changes in cereal and protein meal prices, in turn, have significant implications for livestock industries around the world. Biofuel market developments also affect the US federal budget and international trade negotiations as higher crop prices translate into lower levels of government payments under existing US farm commodity programs.

This paper describes recent developments in US biofuel markets and a new set of global market projections prepared in February 2007 by the Food and Agricultural Policy Research Institute (FAPRI) at The University of Missouri–Columbia and Iowa State University. Assuming there is a continuation of current US policies, developments in petroleum markets are likely to have a large impact on future prices. However, the true impact of high energy prices on food security cannot be fully evaluated assuming ‘normal’ weather and demand in a deterministic analysis because it fails to highlight the impacts on future commodity price volatility. Stochastic analysis will be used to demonstrate the wide range of possible outcomes for biofuel and agricultural markets, and identify key market drivers. While further rapid growth of the biofuel industry is certainly possible under the right conditions, it is possible to identify circumstances that could sharply curtail industry expansion.

Introduction

The recent surge in energy prices, uncertainty about their future direction and changes in government energy policies around the world have impacted production. Transportation costs for agricultural commodities and spurred investment in production of biofuels from basic agricultural commodities also affect production. Energy prices have historically played a role in commodity markets through their effect on input costs in the production process and on transportation. Agriculture’s small share of total demand for energy used to mean that impacts could be isolated and examined within the sector. Now, with the introduction of additional commodity demand through the production of biofuels, it substantially increases the effect of energy price movements on agriculture markets tying the two sectors closer together. Increased commodity demand from the energy sector has implications for patterns of trade and volatility in world food and feed prices, potentially impacting countries which import large quantities of food and feed along with citizens who spend a larger portion of their budget on these items.

The introduction of biofuels has the potential to raise the income of the world’s farmers, spur production and investment, and to shift energy use to renewable sources. It also has the potential to raise food costs and increase competition for supplies. This can have significant impacts on food security and the vulnerability of food insecure populations. To better understand the issues of food security in the context of increasing energy prices, it is necessary to quantify exactly how energy prices and policies impact food and feed prices, price volatility, production, consumption, trade patterns and trade volumes.

A careful assessment of the rapid expansion of corn-based biofuels in the US provides significant insights to the greatly expanded linkages between petroleum prices and commodity prices. The impacts on world market behavior can also be quantified. A comprehensive treatment of the new linkages between energy and commodity markets, along with the impacts of the biofuel surge, show the degree to which the new industry has increased levels and volatility of commodity prices for the foreseeable future. Stochastic analysis shows a wide range of potential outcomes and rising levels of price volatility.

Ethanol Extension to the Stochastic Model

The FAPRI stochastic model of the US agricultural sector is a non-spatial, partial equilibrium model covering markets for major grains (wheat, corn, rice, sorghum, barley and oats), oilseeds and their derivatives (soybeans, rapeseed, sunflower seed, peanuts, and palm oil), cotton, sugar, beef, pork, poultry, and dairy products. Its structure is a simplification of the FAPRI deterministic modeling process with reduced form equations used to simulate trade in the rest of the world normally covered by international country and regional models, and aggregating domestic supply regions to a single national market. With these simplifications the model still contains over 1,000 equations representing US crop and livestock supply, demand, trade and prices. The model also contains sector aggregates, such as government expenditures on farm programs, net farm income, agricultural land values and consumer food price indices (FAPRI 2005). The model has been enhanced extensively with ethanol and biodiesel markets and data.

The crops sector is modeled through behavioral equations representing crop acreage, domestic feed, food and industrial uses, and stock holding and trade. Similarly, the livestock sector is modeled through behavioral equations determined by animal numbers, production of meat and dairy products, consumption, and stock holding and trade. To be able to analyze alternative proposals, the FAPRI baseline assumes a continuation of current policies. Notably, in this year's baseline, the blenders credits for ethanol of $0.51 and biodiesel of $1.00, schedule to expire in 2010 and 2008, as well as the ethanol tariff of $0.54, scheduled to expire in 2008 are assumed to be extended.

Equations in the biofuels module tie into industrial demands for grains and oilseeds, and behavioral equations determining ethanol and biodiesel production, consumption and trade in products and blends with other motor fuels. The model solves for the set of prices that brings annual supply and demand into balance in all markets. Because the biofuels industry is rapidly growing and very little data is available for the period of rapid expansion, many of the equations are synthetically derived by using elasticity assumptions and calibrating to recent history.

In the FAPRI US model, the supply of ethanol is composed of beginning stocks, net imports and production. Ethanol production is separated into that derived from dry and wet mills. In the case of traditional dry mill, distiller's grains (wet and dry) are the primary byproduct of value. In the case of wet mills, the byproducts include corn oil, corn gluten feed and meal. Most of the new ethanol plants using corn as a feedstock are dry mills, but the model allows wet mills to switch between producing starch, or high fructose corn syrup, and ethanol. Since most of the expansion of ethanol production is occurring with dry mills, the model description presented will focus on this area. Ethanol plant costs and returns are based upon USDA estimates (USDA). Dry-mill net returns (over operating costs) per bushel, denoted NRT, are calculated as the wholesale ethanol price, denoted WETHP, multiplied by the number of gallons of ethanol per bushel, denoted ETYLD; plus the distillers' dried grains (DDGs) price, denoted DDGP, multiplied by the number of pounds of DDG's per bushel, denoted DGYLD; minus the corn price, denoted CORNP; minus the natural gas cost, denoted NATP; minus the other costs of conversion, denoted OVC (equation 1).

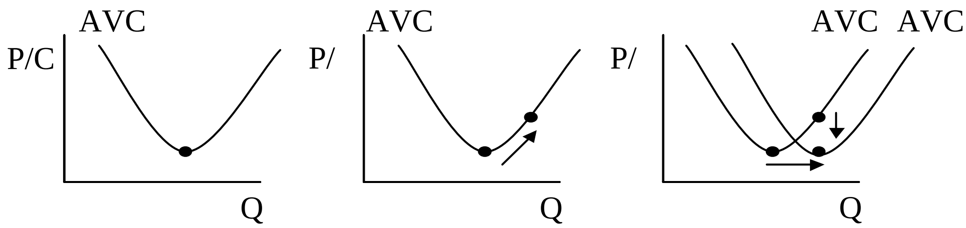
$$NRT_t = f(\ CORNP_t, NATP_t, OVC_t, DDGP_t, WETHP). \qquad (1)$$

Dry mill ethanol production, denoted PROD in equation 4, is not directly determined, but rather as the product of available productive capacity, denoted CAP in equation 2, and capacity utilization rates, denoted CAPUTL in equation 3. This structure is used because plant construction time exceeds one year (period) and once the plant is built, its useful life is expected to be at least ten years. Given the multi-period nature of investment in biofuels production facilities, CAP is estimated as a function of historical net returns with a modest impact of returns from the current year. The current year net returns are included in the specification with a very low elasticity to reflect the limited ability to accelerate the completion of plants already under construction under higher ethanol returns. There is a greater response in capacity to net returns in previous periods reflecting the period of investment decision and an average 18 month construction time for new facilities. Responsiveness peaks in period t-2. The lagged dependent variable reflects the long term nature of the capacity investment stabilizing capacity shifts from year to year (i.e. once a plant is built, the capacity is available for its useful life). The capacity in year t-10 is included to capture the retirement of older facilities but plays a small role given the relative youth of the industry as a whole. Even though capacity exists, it is possible that it may not be fully utilized depending upon the plats ability to cover its variable cost of production. Capacity utilization, denoted CAPUTL, is only a function of current period net returns (see equation 3).

$$CAP_t = f(\ NRT_t, NRT_{t-1}, NRT_{t-2}, NRT_{t-3}, NRT_{t-4}, CAP_{t-1}, CAP_{t-10}). \qquad (2)$$
$$CAPUTL_t = f(\ NRT_t). \qquad (3)$$
$$PROD_t = CAP_t \times CAPUTL_t \qquad (4)$$

Capacity utilization rates are synthetically specified in a logistic form, bounding utilization rates between 0% and 100% and varying the responsiveness to changes in price depending on current utilization rates. By example, as shown in Figure 1, a sustained increase in ethanol prices would increase utilization rates in the current period, but in subsequent periods additional capacity would be built and utilization rates would return to their 'natural' rate. Additional production of ethanol from other grains besides corn and cellulosic based ethanol are included in production totals.

Figure 1: Capacity and Utilization Behavior



Retail ethanol demand is segmented by use and blend rates and tied to motor fuel use. The demand portion of the ethanol model captures both the retail level (consumers) and wholesale level (blenders) and considers the total retail market for motor fuels. Retail ethanol demand is segmented by use and blend rates, and tied to motor fuel use. Retail ethanol demand is broken down into demand for ethanol as an additive, the 10 percent ethanol market (E10) less the additive market, and the 85 percent ethanol market (E85).

Motor fuel use, denoted MFU in equation 5, is estimated as a function of the unleaded gasoline retail price, denoted UGRP; income, denoted INC; and a very small substitution effect from the retail price of ethanol, denoted RETHP. The unleaded gasoline retail price, denoted UGRP, is a function of an exogenous petroleum price index, denoted PPIP, which is closely related to the price of crude oil. Motor fuel use and the retail unleaded gasoline price then impacts the demand for ethanol in various formulations.

$$MFU_t = f(UGRP_t, RETHP_t, INC_t). \qquad (5)$$

The segment of additive ethanol demand, denoted ETADD largely reflects the replacement of the oxygenate Methyl tertiary-butyl ether, denoted MTBE, in select markets and is blended at 10% or less in motor fuels. Regional blends in California include a 5.7% oxygenate mix. Additive demand is a function of the wholesale ethanol price adjusted for the blenders' tax credit of $0.51 cents per gallon, denoted ETTAX; motor fuel use multiplied by the ethanol additive share required to meet oxygenation requirements, denoted ETADSHR, and MTBE use. Demand for ethanol as an additive and replacement for MTBE in regions with oxygenation mandates results in a relatively inelastic response to wholesale ethanol prices. In the additive market, ethanol use is mandated and behaves in a complimentary relationship with regular unleaded gasoline. As regular unleaded gasoline prices increase, total motor fuel use declines and so does the demand for ethanol as an additive.

For the non-additive use, demand is broken into retail market potential and penetration for the E10 and E85 markets. Market potential for the two blends differs on the quantity of ethanol demand possible, with up to 10 percent inclusion for E10 and up to 85 percent inclusion for E85. The E10 blend can be used in the vast majority of motor vehicles on the road today making the potential market, denoted E10MKT in equation 7, 10% of motor fuel use less the ethanol additive share required to meet oxygenate requirements. The penetration of E10 into the market, denoted E10PEN in equation 8, is a function of the ethanol to regular unleaded price ratio. In some states, gas pumps explicitly display signs that state ethanol is included. In other states, located in the northeast, gas pumps do not label fuel as containing ethanol. So, consumers may not be making a choice with full information. Labeling, along with the relatively low inclusion rate and ethanol octane boost, makes it unclear whether consumers will fully be able to distinguish the fuel economy difference between the additive level and the E10 level. As such, they may not be as responsive to the ethanol/regular unleaded gasoline price ratio over a certain range.

When the ratio of retail ethanol prices to retail unleaded gasoline prices is above 75%, only the first term applies and is relatively inelastic. When the ratio falls below 75% demand becomes much more responsive as the price ratio more fully reflects their relative energy content, ethanol contains 65-70% of the energy value of gasoline, with some positive adjustment for the value of the higher octane in ethanol. Therefore, as the price ratio falls below 75%, ethanol is more competitive with regular unleaded gasoline and consumer responsiveness increases. At this point, the second term in the equation bends the E10 demand from a relatively inelastic position to a very elastic demand that is highly responsive to price. Total ethanol demand in the E10 market, E10D, is then a product of market potential and market penetration (see equation 9).

The market potential for E85, denoted E85MKT in equation 10, differs as its use is limited to special ‘flex fuel’ vehicles. Therefore, the market is limited to the number of such vehicles on the road, which is expected to increase over time, denoted TREND. It may accelerate or slow depending upon the price ratio of ethanol and regular unleaded gasoline. As compared to E10, all consumers are clearly aware of the inclusion of ethanol and can more clearly distinguish the difference between the fuel economy of E85 and regular unleaded gasoline. Thus, they will likely be much more responsive to the ethanol/regular unleaded gasoline price ratio. E85 market penetration, denoted E85PEN in equation 11, is specified as a function of the same variables as E10 market penetration, but with different responsiveness and a lower price ratio of 70 percent to reflect better labeling. The acceptance and use of E85 accelerates as ratio of retail ethanol to unleaded gasoline prices falls below 70 percent, but is very unresponsive at ratios above this point. E85 demand, denoted E85D in equation 12, is then a product of market potential and market penetration.

Total ethanol demand, denoted ETDMD in equation 13, then becomes the maximum of the aggregated demand across the additive, E10 and E85 markets or the mandated quantities under the Renewable Fuel Standard (RFS) (subtracting biodiesel use, denoted BIODSL).

$$ETADD_t = f((WETHP_t - ETTAX_t), MTBE, MFU_t * ETADSHR). \qquad (6)$$

$$E10MKT_t = f(MFU_t, ADDAJ_t). \qquad (7)$$
$$E10PEN_t = f(RETHP_t/UGRP_t, \max(0,.75 - RETHP_t/UGRP_t)). \qquad (8)$$
$$E10D_t = E10MKT_t \times E10PEN_t \qquad (9)$$

$$E85MKT_t = f(E85MKT_{t-1}, TREND_t, \max(0,.75 - RETHP_t/UGRP_t)). \qquad (10)$$
$$E85PEN_t = f(RETHP_t/UGRP_t, \max(0,.7 - RETHP_t/UGRP_t)). \qquad (11)$$
$$E85D_t = E85MKT_t \times E85PEN_t \qquad (12)$$

$$ETDMD_t = \max((ETADD_t + E10D_t + E85D_t), RFS\text{-}BIODSL) \qquad (13)$$

Ethanol ending stocks, denoted ETSTK, are specified as a function of wholesale ethanol price (reflecting speculative demand) and ethanol production (reflecting transaction demand). Net imports of ethanol, denoted ETNIMP, are specified as a function of simulated world ethanol prices and domestic prices adjusted for the $0.54 import tariff. The wholesale ethanol market closes on the standard supply equals demand identity (equation 14).

$$ETSTK_{t-1}+ETPROD_t + ETNIMP_t = ETDMD_t + ETSTK_t \quad (14)$$

Ethanol wholesale and retail prices are linked through an identity which includes the blenders' tax credit of $0.51 a gallon and a wedge taken from the wholesale to retail price spread of unleaded gasoline (see equation 15).

$$RETHP_t = WETHP_t-ETTAX+UGRP_t-UGWP_t. \quad (15)$$

The structure of the biodiesel model is similar to ethanol, but more limited in scope given the size of the industry. The smaller scale of biodiesel production leads to some simplifications so demand is not segmented into additive and blend markets. Biodiesel demand explicitly includes the $1.00 tax credit to biodiesel blenders. Capacity and capacity utilization in the biodiesel markets is determined by net returns for biodiesel plants as described by the National Renewable Energy Laboratory (Tyson). The market is driven largely by soybean oil as a feedstock but also includes rapeseed oil, and other oils and fats.

Uncertainty and Volatility

Uncertainty is introduced into the model by drawing on distributions of selected exogenous variables and historical error terms for behavioral equations such as petroleum prices and domestic demand, trade and yields (Westhoff 2006). The partial stochastic baseline utilizes the historically correlated distributions of crop yields and correlated distributions of the errors in key demand equations including exports, to construct 500 possible futures based on the historical variability in these equations. For exogenous variables such as petroleum prices, historic patterns of price movements are replicated in the future (figure 2). For the primary behavioral equations, the historic deviation for the equation solutions, such as deviations from trend yields, are used to create a distribution of errors. This distribution of errors is then randomly drawn from and used with correlated draws on other error terms in order to solve the model for 500 alternative solutions over a ten year period. Figure 3 shows 2 of 500 solutions for corn. It is only a partial stochastic approach in that not all exogenous variables and equation error terms are included. However, partial stochastic analysis provides a perspective on the potential variability in results which can be compared with historical variability.

Figure 2. Uncertainty of Petroleum Refiners Acquisition Price

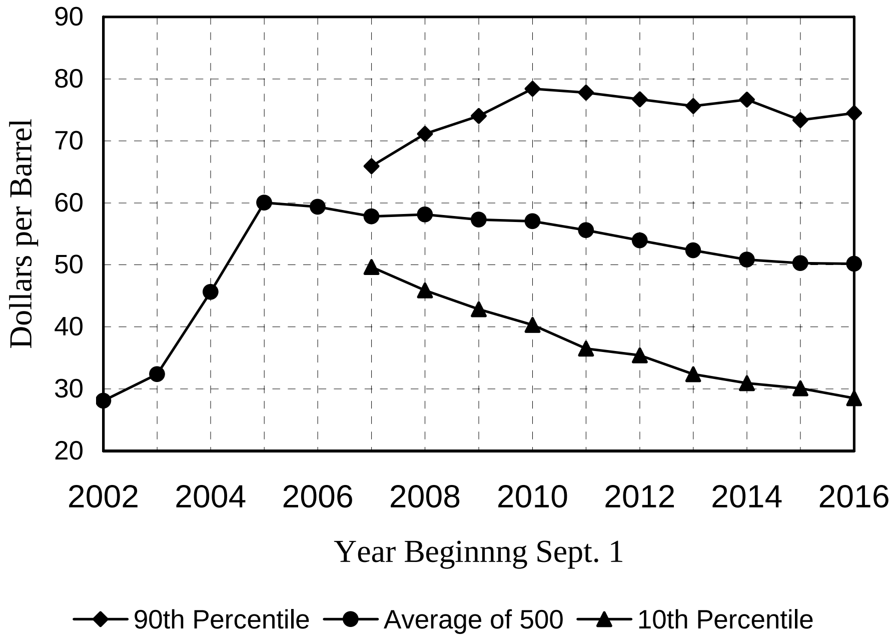
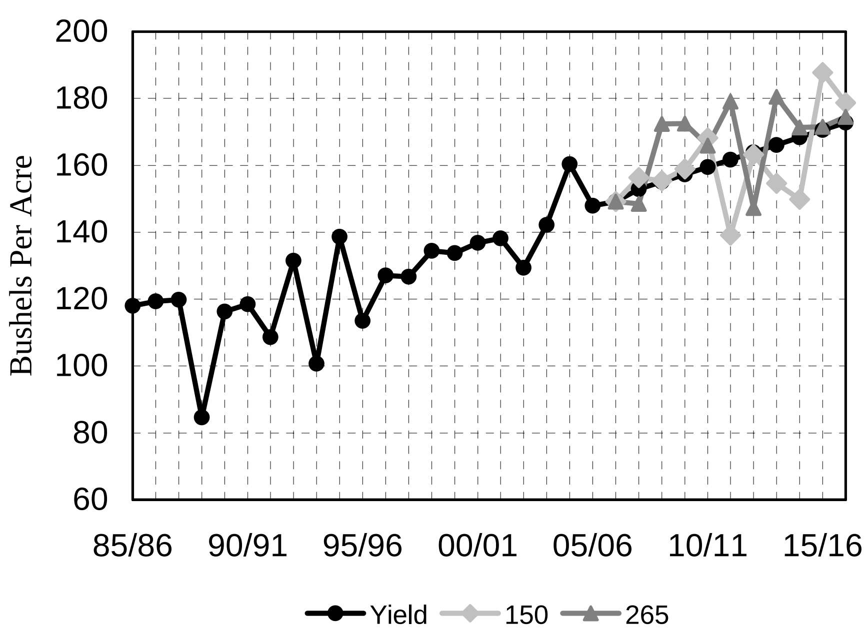
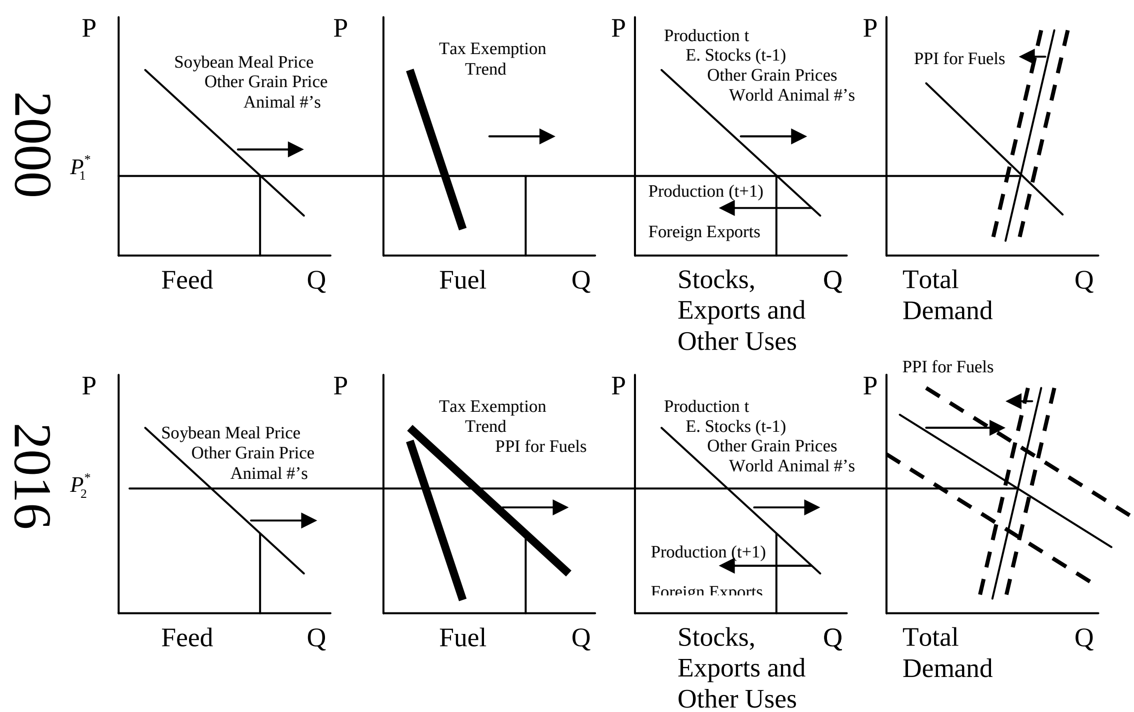


Figure 3. Yields uncertainty in stochastic, maize example



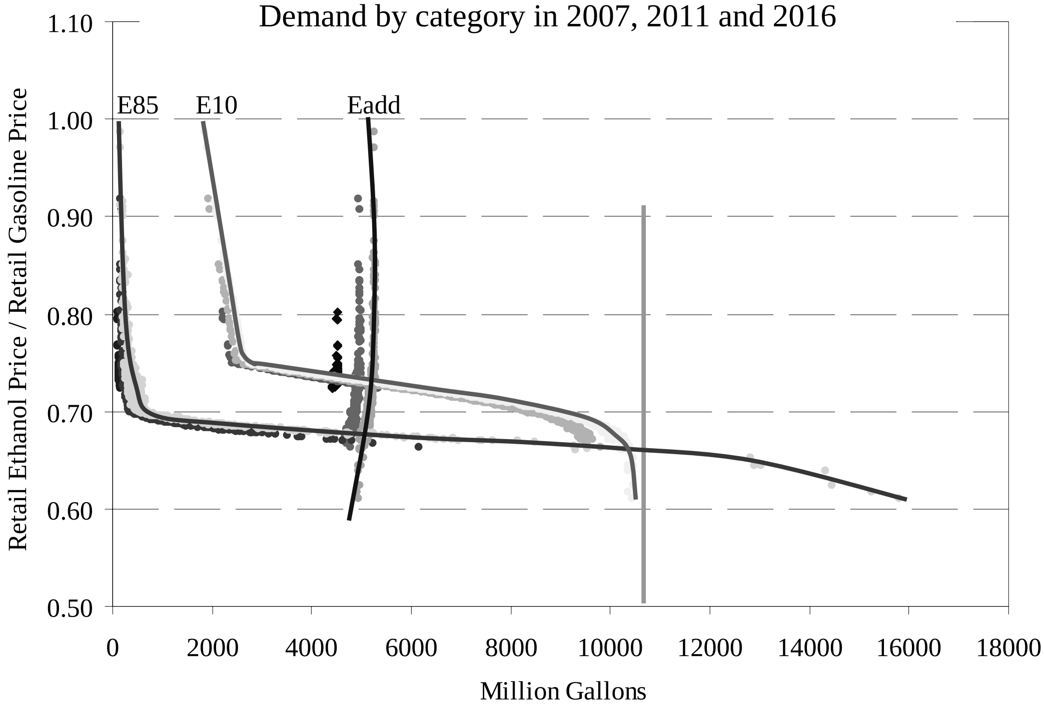
While uncertainty is introduced through petroleum prices, domestic demand, trade and yields, volatility, or the relationship among some variables, has changed considerably with the rapid increase in biofuels production. There are three key factors driving the changes in price volatility. First, the growing demand for corn reduces stocks and increases the price impacts of any supply or demand shock. When stocks approach 'pipeline' levels, price responsiveness naturally decreases, increasing price volatility. Second, unlike the past when petroleum prices primarily affected commodities primarily through input costs, they now have a major impact on the demand side through biofuel linkages (Figure 4). As petroleum prices are increasingly linked to corn demand through the presence of ethanol production, variation in those petroleum prices results in an increase in the magnitude and frequency of shocks to the corn demand curve. This linkage to petroleum prices adds an important new source of price volatility in commodity markets and corn more specifically. Finally, a structural change that potentially reduces price volatility is that the large new demand component (corn for ethanol production) is relatively price elastic over certain ranges. It is therefore increasing the aggregate demand elasticity for corn. It is an empirical question to determine the relative importance of each of these and the net result on price volatility. So far, results indicate the net effect is an increase in price volatility, but is subject to model assumptions. As more information becomes available, changes in responsiveness may occur.

Figure 4: Corn Sector Impacts



The demand for corn for fuel, as a derived demand, is subject to demand factors in ethanol markets. Ethanol demand at the retail level is specified as non-linear with policies and preferences creating inelastic portions of the aggregate demand curve. The demand curves for each category of use are illustrated by tracing out the stochastic solutions for the years 2007, 2011 and 2016 (Figure 5) from the FAPRI model. Following the discussed specifications, ethanol as an additive (Eadd) is shown as highly inelastic because its use is mandated and moves with total motor fuel demand in specific geographic locations. Demand for ethanol as an additive bends backward at low prices as the low inclusion rate fuel is substituted with fuels mixed at a higher ethanol inclusion rate. When the ratio of ethanol prices to gasoline prices approaches the ratio of their energy content, plus the value of increased octane, demand for E10 becomes much more elastic. The use of E10 becomes less responsive again at high levels of use as standard vehicles, in aggregate, approach the maximum inclusion rate of 10%. The point at which demand for E85 becomes more elastic is lower than that for E10 as its energy content is also lower (due to its higher ethanol content). In the short run, demand for E85 is limited by the number of ‘flex fuel’ vehicles in use. But, it becomes highly elastic in the long run when ethanol prices fall relative to gasoline prices.

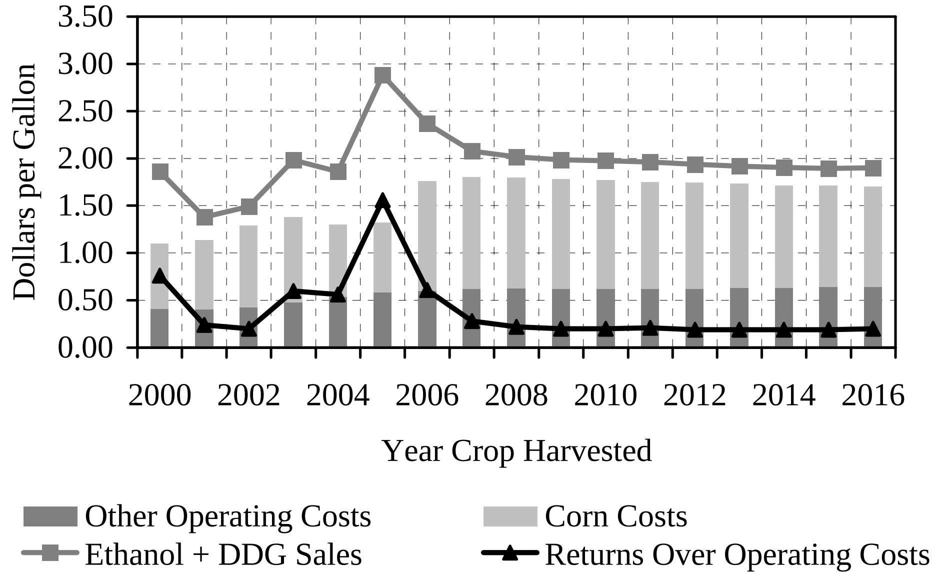
Figure 5: Retail Ethanol Demand Curves by Inclusion Rate
Demand by category in 2007, 2011 and 2016



Ethanol costs and returns under uncertainty

Net-returns to ethanol production, as shown in equation 1, is a function of the input prices of corn and other inputs and output prices for ethanol and DDGs. Corn is the primary input cost and ethanol the primary source of receipts. While ethanol margins have been significant in 2005/06 and 2006/07, they are expected to narrow as MTBE replacement is completed and corn costs rise. Figure 6 shows the stochastic average of costs and returns from the 2007 FAPRI stochastic baseline. With ethanol replacing MTBE in a number of regions, ethanol had been selling at a volume premium to unleaded gasoline. For ethanol demand to expand significantly beyond current quantities, it must compete with unleaded gasoline based upon its energy value.

Figure 6. Ethanol Dry Mill Costs and Returns



With increased demand, corn prices are expected to rise, further cutting into ethanol returns which are expected to fall to $0.20 per gallon (figure 6). Net-returns, as reported, are a measure of receipts over operating costs. Therefore, the addition of capital costs would reduce profits to near zero. This sends a strong signal to the sector to slow or stop capacity growth. Because of the time frame of plant construction, even a near zero profit signal in the 2007/08 crop year will lead to capacity increases in the next few years as plants already under construction are completed (figure 7). Dry mill returns to operating costs results are still subject to uncertainty from corn yields, petroleum prices and other stochastic variables (figure 8). Examining the 500 alternative outcomes, few of the outcomes result in negative returns over operating costs, suggesting high capacity utilization rates are likely. However, the majority of the outcomes for 2009 and beyond show net returns less than $0.20 per gallon. This should limit investment in additional capacity. Clearly, these results are heavily dependent upon the underlying policy assumptions, extension of blenders credits (Westhoff 2007) and petroleum prices (figure 2). Lower petroleum prices or significantly higher corn prices reduces net returns and utilization rates.

Figure 7. Dry Mill Ethanol Capacity

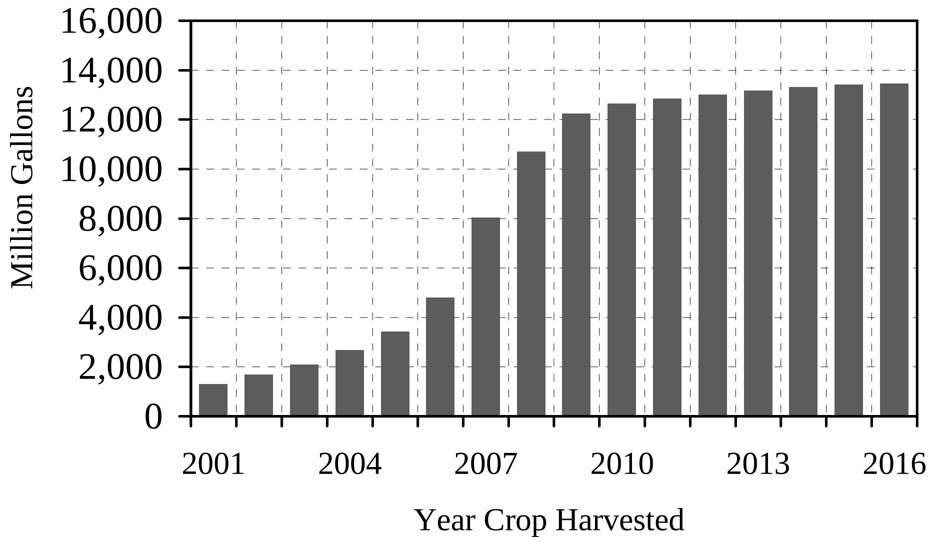
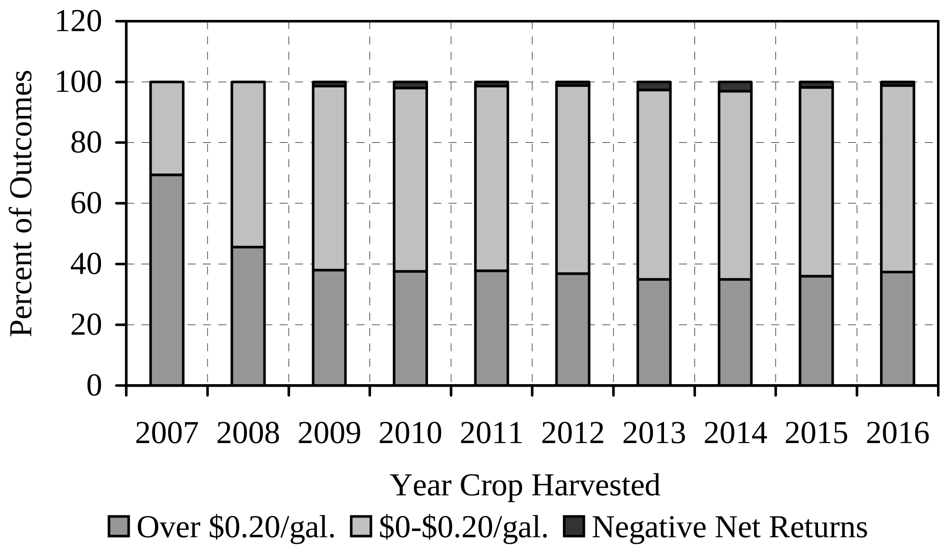


Figure 8. Ethanol Dry Mill Returns over Operating Costs

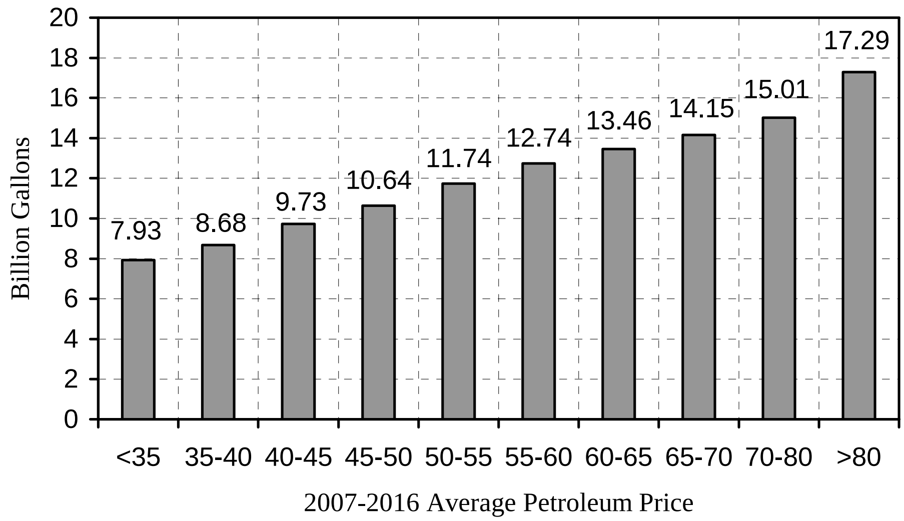


Impact of petroleum prices on crop prices

Stronger demand for corn to produce ethanol has resulted in higher prices for corn and other crops in world commodity markets. It is clear that increased biofuel production derived from agricultural commodities has far reaching implications across a variety of commodities. Changes in cereal and protein meal prices, in turn, have implications for food and livestock feeding industries around the world. Biofuel market developments even affect the US federal budget and international trade negotiations as higher crop prices translate into lower levels of government payments under existing farm commodity programs. Figure 9 shows the impact of petroleum prices on ethanol production and, thereby, on crop and vegetable oil prices. Through competition for commodities on the demand side and for land on the supply side, other commodity prices also increase and are made more volatile.

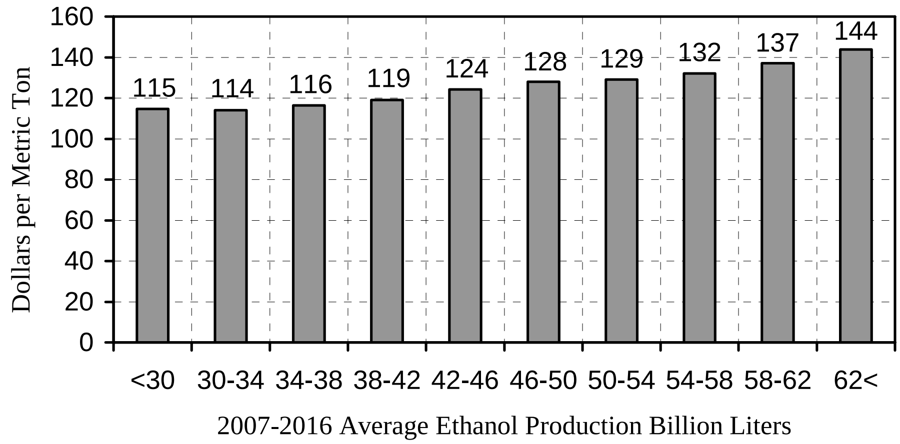
In the stochastic model, higher petroleum prices and ethanol plant net returns are associated with greater levels of ethanol production (figures 9 and 10). In the distribution of stochastic outcomes, ethanol production is more than twice as great when the 2007 to 2016 average petroleum prices are over $80 per barrel compared to when they are under $35 per barrel. It should be noted that the difference is even larger at the end of the projection period when the capacity has more time to adjust to prices because it is potentially less constrained.

Figure 9. Ethanol Production, 2007-2016 Avg.



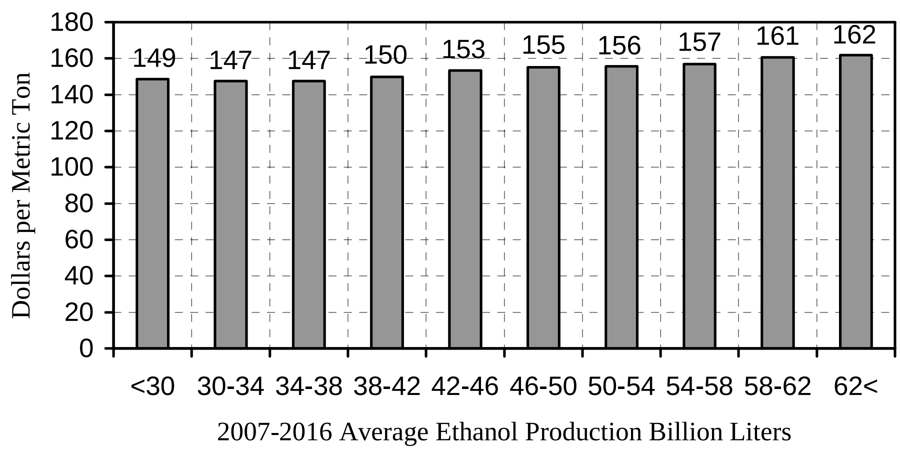
The average projected corn price across all 500 outcomes for the average of the years 2007-2016 is 124.20 per metric ton. As shown previously, high petroleum prices drive up ethanol production, increasing corn demand as well as corn production costs, both of which increase the price of corn. The relationship is not perfect, however, as other stochastic factors such as yields and export demand impact the price of corn as well (Figure 10).

Figure 10. Distribution of 2007-2016 Avg. Corn Farm Prices



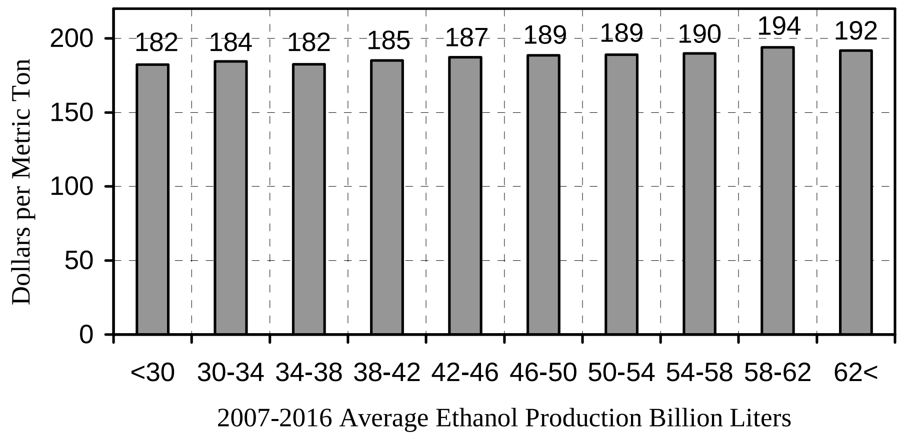
The average projected wheat price across the 500 outcomes for 2007-2016 is $152.76 per metric ton (Figure 11). Rising corn prices, resulting from increased ethanol production, increases competition for wheat acreage in the corn-belt and planes states, reducing acreage and increasing wheat prices. Wheat prices are also tied to corn prices through substitution in feed rations. The total effect in wheat is smaller than the impact for corn.

Figure 11. Distribution of 2007-2016 Avg. Wheat Farm Prices



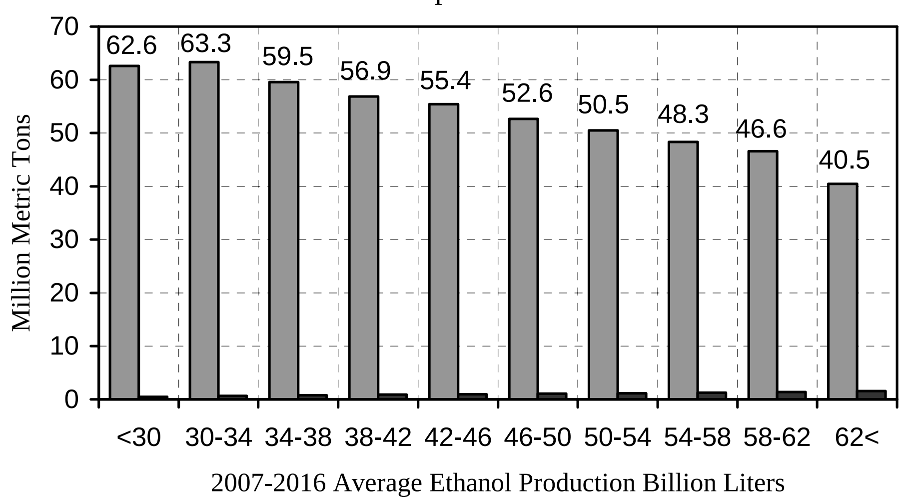
The average projected rice price across 500 outcomes for 2007-2016 is $186.85 per metric ton (figure 12). Increased acreage competition and commodity prices drive up rice prices with increased ethanol production, reducing rice area and increasing rice production. The price impacts for rice are smaller than for both corn and wheat due in part to geography and nonconvertible capital equipment. While the US is a significant exporter of rice, there are sizable exporters elsewhere in the world.

Figure 12. Distribution of 2007-2016 Avg. Rice Farm Prices



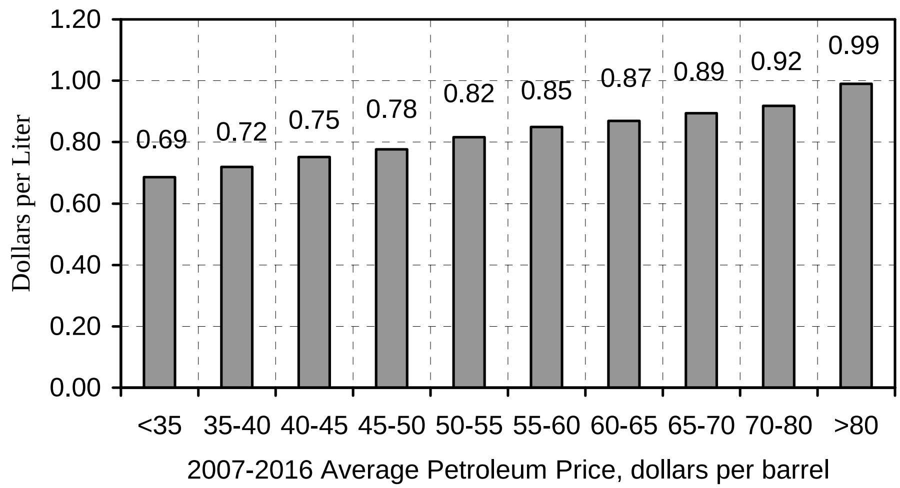
Higher levels of ethanol production are related to lower exports of corn as available supplies are diverted to the production of biofuels (figure 13). The US dominates international trade in corn so changes in exports, given the range of outcomes for petroleum prices, have a significant corn trade impact. At the same time, DDG exports linked to higher ethanol production, offset little of the reduced corn exports.

Figure 13. Distribution of 2007-2016 Avg. Corn, DDG Exports



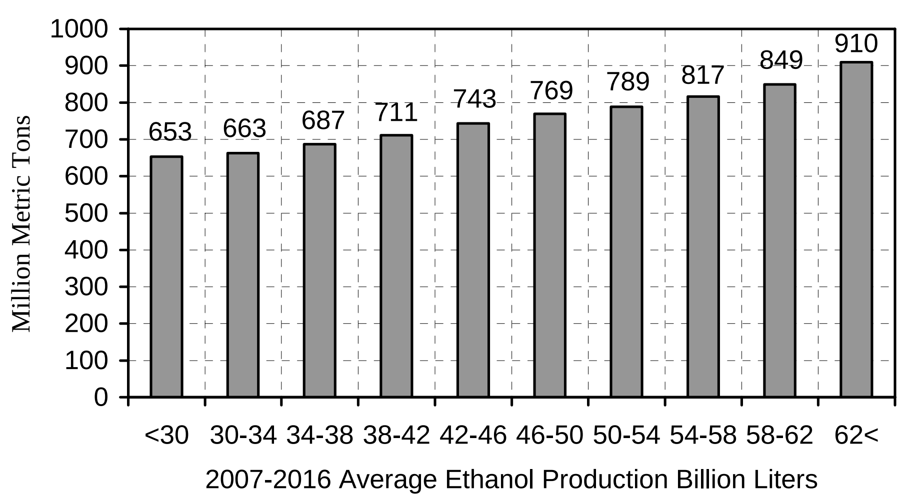
Higher petroleum prices which are associated with higher ethanol prices also result in higher biodiesel prices (figure 14). The 10 year average biodiesel price at the plant, across all 500 outcomes is $0.82 per liter. It is worth noting that these results assume extension of the federal tax credits that support producer biofuels prices and returns (Westhoff 2007).

Figure 14. Biodiesel Price, Plant, 2007-2016 Avg.



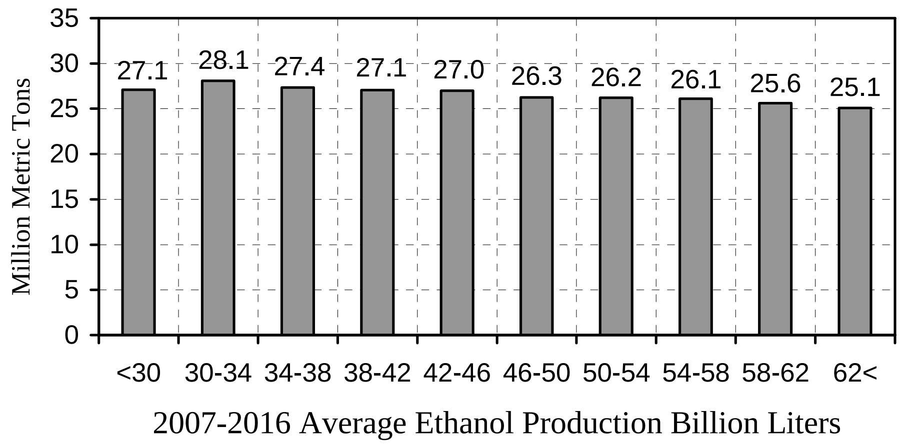
Due to both supply and demand effects (Figure 15), soybean oil prices rise with higher ethanol production. Acreage shifts to corn reduce soybean acreage and push up the price of soybeans and soybean oil. DDG use in livestock rations, while primarily displacing corn, displace a portion of soybean meal in the ration, driving down soybean meal prices and pushing up soybean oil prices.

Figure 15. Distribution of 2007-2016 Avg. Soyoil Price



Increased ethanol production is associated with fewer soybean acres and smaller exportable supplies along with higher soybean prices faced by importing countries (Figure 16). The impact on soybean trade is limited.

Figure 16. Distribution of 2007-2016 Avg. Soybean Exports



Conclusion

The rapid growth of corn based ethanol production has added a significant new demand to corn and related markets. A careful assessment of the rapid expansion of corn-based biofuels in the US provides significant insights to the greatly expanded linkages between petroleum prices and commodity prices. The elastic nature of the new corn demand category would, in isolation, raise and stabilize corn prices. However, the linkage between petroleum prices and corn demand has been strengthened, adding volatility to corn markets. Our results so far indicate the net effect is an increase in price volatility, but it requires continual analysis as more information becomes available. A comprehensive treatment of the new linkages between energy and commodity markets, along with the impacts of the biofuel surge, show the degree to which the new industry has increased levels and volatility of commodity prices for the foreseeable future. Stochastic analysis shows a wide range of potential outcomes and rising levels of price volatility.

Stronger demand for corn to produce ethanol has translated into higher prices for corn and other agricultural commodities in world markets. Likewise, increased demand for vegetable oil to be used to convert to biodiesel will result in higher vegetable oil prices and increased supplies of oilseed meal. It is clear that increased biofuel production derived from agricultural commodities has far reaching implications across a variety of commodities. Changes in grain and protein meal prices, in turn, have significant implications for livestock industries around the world. Our analysis and results indicate that the potential for bioenergy as a motor-fuel substitute, at least over the next decade, is highly dependent on the level of petroleum prices and on government policies. In any case, it adds a new source of volatility to cereals and vegetable oils markets in particular, and food markets in general.

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