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New Challenges in Agricultural Modeling: Relating Energy and Farm Commodity Prices

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New Challenges in Agricultural Modeling – Relating Energy and Farm Commodity Prices

Summary

We use forward-looking FAPRI-MU economic models to assess the relationships between energy and agricultural markets. We include current policy and higher projected biofuel volumes as key factors that have altered these relationships, undermining the value of studies based purely on historical relationships.

In the past, energy prices affected costs of producing, transporting, and processing agricultural commodities. Rising prices of petroleum and natural gas were expected to lower quantities of agricultural commodities overall and result in higher prices, with certain adjustments among commodities. In the last decade, biofuels have increased dramatically. Corn purchases for fuel alcohol production constitute 40% of 2010/11 domestic use in current FAPRI-MU projections, as compared to 8% just 10 years ago. In these projections, the share of biodiesel use in total soybean oil domestic use rose from 0% to 19% over this same period. The role of biofuels in US transportation fuel markets has also grown. Ethanol's share of the US motor gasoline market rose from 1.4% (0.9% in energy equivalent terms) in 2000/01 to 9% (6%) in 2010/11. Biodiesel's share of the diesel market rose from 0% to 2.4%.

We use economic models to simulate how markets will evolve in light of these new realities. We take into account greater volumes of biofuels than were seen in the past, as well as the fundamental causes for this increase – namely, potentially high petroleum prices and biofuel policies. We use output from models representing selected US agricultural commodity, biofuel, and energy models, with varying degrees of representation of the rest of the world, to estimate the relationships among these markets in the future.

We find:

- If output of major crop and livestock products rises 1%, petroleum and natural gas prices increase very little.
- If biofuel use increase 1%, then gasoline price changes by -0.30% in the short-run. The effects of a sustained increase after 10 years are -0.14% in the gasoline price and -0.03% petroleum price, with diesel price almost unchanged. The effects of 1% more biofuel use on the natural gas price is positive, but small.
- If petroleum price increase 1%, then corn price is up by 0.20% and the soybean oil price rises by 0.23% in the short-run. This is similar to the effect of a sustained increase after 10 years, after supplies of all crops and biofuel refiners adjust, but other agricultural

commodity prices also rise. The effect on consumer food expenditures after 10 years is an increase of 0.14% and, while falling in the first year, farm income rises by 0.11% in the long run.

- New work suggests that a 10% higher diesel fuel price increases costs of crop production by 2.1-3.5%, including 2.2% for corn, 2.3% for soybeans, 2.7% for wheat.
- 1% natural gas price increase causes very small short-run effects on crop prices. Crop and ethanol production responds to higher input costs if the increase is sustained over 10 years, with a net effect of lower crop prices. Both forces result in lower net farm income, which changes by -0.14%.
- New work suggests that a 10% higher natural gas price increases crop production costs by 0.3% to 1.2% through its effect on fertilizer prices, with corn and wheat costs increasing the most and soybean costs the least. An electricity price increase of 10% would have an additional impact of 0.5-0.6% on production costs of most crops, save cotton costs which are 1.2% higher.

The nature of these relationships varies depending on whether or not the biofuel use mandates are binding. The petroleum price impacts on agricultural markets are most sensitive. If the mandates are not binding, then demand for biofuels that substitute for petroleum products will respond to price changes at all market levels. Biofuel demand shifts will be transmitted back to biofuel processors and, through them, to feedstock and other agricultural commodity markets. We find that these demand-side effects overwhelm the traditional supply-side impacts of petroleum prices on agricultural commodity markets. Without binding mandates, petroleum price increases means more land devoted to crops and higher crop farm income.

Binding biofuel use mandates sever these relationships. If biofuel use mandates are binding, then petroleum price changes still have effects on biofuel demand, but these effects cannot cause changes in the quantities used. Consumer desire to buy more or less biofuel is not communicated to biofuel refiners, nor to feedstock suppliers. With binding mandates, there is little impact on biofuel refiners' demand for agricultural commodities. In this context, the traditional supply-side effects dominate the effects of petroleum price changes on agricultural commodity markets, implying less land overall, and less to corn, at lower crop farm income.

Our results are contingent on our representation of the underlying behavioral relationships (such as the scope for expansion of fuels that are mostly ethanol), technology (cellulosic biofuel production), and policies. Refinements in our economic models help to overcome other limitations. For example, new stochastic simulation methods address the complexity of comparing marketing and calendar year data, and our estimated impacts of energy price on agricultural production costs are also under revision.

Contents

Introduction

Biofuel demand for feedstocks has led to dramatic changes in applied analysis of agricultural commodity markets and specifically their interactions with energy markets. Whereas ethanol and biodiesel made from corn and soybean oil, respectively, represented very small shares of total markets in the United States a decade or more ago, their contribution has become substantial, and is still growing. The old consensus held that higher energy costs could cause lower quantities of crops, because of rising crop input costs and weakening derived demands for agricultural commodities as processing costs increased. A high petroleum price caused lower crop production, in aggregate, and lower farm income. The new view suggests that higher energy prices, particularly that of petroleum, might lead to higher crop production and farm income.

Initial research into the implications of biofuels for agricultural commodity market analysis culminated in the argument that long-term relationships would drive biofuel and corn prices. This reasoning suggested that consumer would be willing to buy all available ethanol at a price equivalent to the gasoline price. Analysts calculated a break-even corn price, taking into account ethanol processing, differences in energy content, policy, and other factors. This reasoning would suggest that analysts could take a petroleum price as given, then derive the equivalent corn price. Given that price, whatever corn produced and not used for other purposes, such as feed or exports, would go into ethanol.

The long-term view of the link between petroleum and corn markets has been enhanced by a growing understanding of at least two intervening factors. One is the adjustment process. Biofuel refining capacity takes time to build. Infrastructure to deliver biofuels to consumers evolves with market conditions, but not smoothly. Consumers' ability to use biofuels beyond certain limits requires more substantive decisions about what type of car to buy and, as well, their choice to buy biofuels might not be based strictly on questions of energy equivalence.

The second factor is the biofuel mandates introduced in 2005 and amended in 2007. These mandates require minimum levels of use and, unlike tax credits or tariffs, the mandates do not just affect the long-term equivalence between corn and petroleum. Binding mandates that disallow quantities to change can sever the link between petroleum and corn prices.

The background for the debate is not one of certainty and predictability. Energy prices move fitfully, not climb steadily. Weather causes crop yields to range widely. The context is constantly shifting as well because of changes in the US macroeconomic conditions, US agricultural production and biofuel trade, and policy. Long-term tendencies may be swamped by short-term fluctuations.

In this report, we build on a sequence of published papers and reports to quantify how energy markets interact with biofuel and agricultural commodity markets. Our work recognizes short-term adjustment delays and the broader context of variability and uncertainty.

I. US agriculture and biofuel effects on energy

The effects of changes in US agricultural commodity and biofuel markets on energy markets is explored in this section using structural economic models that represent the natural gas market and the markets for petroleum and petroleum products. These models were constructed to estimate how changes in key quantities relating to agricultural commodity and biofuel markets affect energy markets. Agricultural commodity and biofuel production require energy inputs, so they add to petroleum product and natural gas demand. Biofuels are typically substitute fuels that can displace petroleum products.

We do not explore these links based exclusively on historical data by, for example, using statistics to trace out how biofuel use affects petroleum and natural gas prices. We do not believe these measures of the relationships are stable in light of recent events. In particular, ethanol consumption in the US amounted to less than 2 billion gallons until 2002, but about 12 billion gallons of ethanol are expected to be consumed in 2010. Ethanol's share of motor fuel rose from 1-1.5% until 2002 to 9% in 2010. Mandates that require minimum volumes of biofuel consumption will continue to grow, setting a target of 36 billion gallons by 2022. Historical relationships built on data when ethanol represented a very small share of domestic fuel use might not reflect current and future conditions.

We use forward-looking structural models to explore how agricultural commodity and biofuel markets affect selected energy markets. Behavioral equations represent different categories of supply and demand in natural gas and petroleum markets. To the extent we can, historical data are used to inform our representation of behavior. The price adjusts to balance supplies and demands. This approach is consistent with the FAPRI-MU models used to represent biofuel and agricultural commodity markets, and these models interact allowing the models sectors to affect each other. As shown below, ethanol and biodiesel use from the FAPRI-MU biofuel model can displace gasoline or diesel in the petroleum products model, leading to lower petroleum product prices. Changes in area planted to crops will change demands for diesel, gasoline, and natural gas (used to produce fertilizer), causing natural gas prices to rise.

This section uses the models of natural gas and petroleum and petroleum product markets to quantify these impacts in the medium-term future. Experiments are conducted separately, for natural gas and again for petroleum and petroleum products, and each is summarized in its own section.

I.a. Agriculture and biofuel effects on petroleum markets

Petroleum and petroleum product markets are represented for the US and the rest of world (ROW). In each region, petroleum, gasoline, diesel, and residual markets are distinct markets, with their own market-clearing prices. The US model is summarized briefly (Figure 1). Petroleum supply is the sum of beginning stocks, production, and imports. Production depends on the US petroleum price and imports depend on the US price relative to the ROW price. As for demand, ending stocks also depend on the US price, but exports are exogenous. Refining, separated into capacity and capacity utilization, depends on the value of outputs (the sum of product prices weighted by refining yields) less the petroleum price. Refined petroleum, plus other refining inputs that are not shown here, determines the domestic production of each petroleum product. We allow for some further refining of petroleum to increase gasoline output; if the gasoline price rises relative to the residual oil price, then residual oil production will be lower and gasoline production higher because of further refining. Imports, which depend on domestic product prices relative to ROW prices, and beginning stocks supplement production in total supply. Petroleum product demands are disaggregated where appropriate in order to identify two key links to agriculture. First, agricultural sector demand for gasoline and diesel are identified separately. Second, biofuel competes with petroleum products in transportation fuel.[1]

The ROW model is similar to the US model in structure, but only aggregate petroleum product demands are estimated. We do not include the potential for ROW agricultural commodity production or biofuel use to affect petroleum markets. We do not allow for further refining in ROW. Another difference is that many of the parameters in the US equations are estimated over historical data, but ROW elasticities of supply and demand were typically chosen based on a review of the literature.

EIA data are used to represent US petroleum and petroleum product prices and quantities and international prices. IEA data are used for ROW quantities. Data about the role of agriculture in energy markets are taken from Miranowski.[2]

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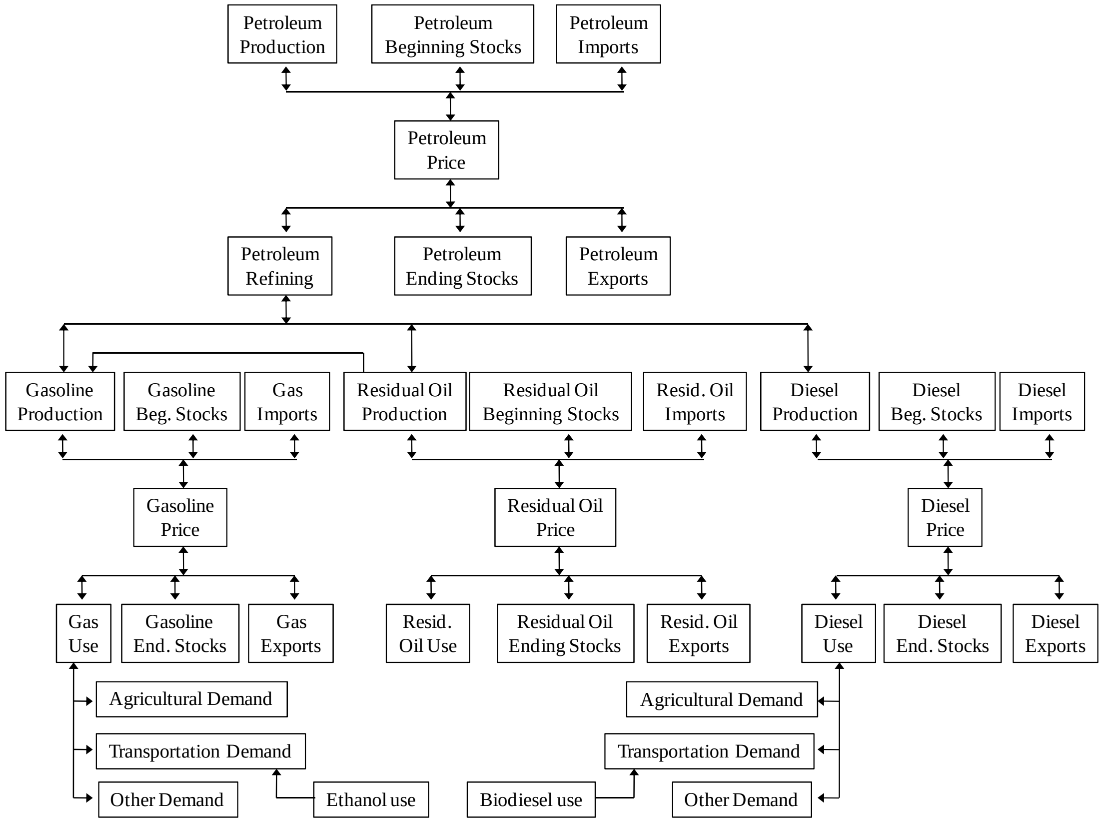
[1] Biofuel use is determined in the FAPRI-MU model system, as discussed later, and includes a share of ethanol used as an additive to gasoline which is a complementary use. However, volumes of ethanol consumed today easily exceed additive use. We expect that the relationship between the gasoline and ethanol is driven by substitution between these two fuels because any additional unit of ethanol must compete to displace gasoline.

[2] Miranowski, "Energy consumption in agriculture" in Outlaw, Collins, Duffield (Eds.), Agriculture as a Producer and Consumer of Energy, CABI Publishing, London, UK, 68-111, 2005.

Figure 1. Flowchart of US petroleum and petroleum products model.



Two key factors influence the magnitude of the impact of agricultural commodity and biofuels markets on petroleum and petroleum product markets. First, there is a question of scale. In our data, the share of agricultural demand for gasoline in total domestic use is less than 1% in the last ten years. The share of agricultural demand for diesel in total domestic use is less than 5%. In 2010, the volume of ethanol is expected to be 9% of the total gasoline and related transportation fuel use, and the share of biodiesel in total biodiesel and diesel transportation fuel use is expected to be about 2%. Biofuel shares doubled in the 3 years from 2007 to 2010. If the volumes of these biofuels grow in the next ten years as required by the mandates, or more if the petroleum price rises quickly, then their shares will probably rise as well. However, if agricultural quantities demanded and biofuel quantities supplied are compared to total petroleum markets, taking into account US and other countries' markets and the full array of goods produced from petroleum, then the shares of agricultural demands and biofuel supplies are smaller.

The second factor is the sensitivity of the market. In the short-run, in particular, the petroleum and petroleum product markets are characterized as extremely inelastic. Thus, a small percent change in quantities of demand or supply can cause larger proportional changes in prices. Given time to respond, producers, refiners, and consumers adjust, and their responses moderate the price effects. However, our survey of the relevant literature suggests that petroleum supply remains inelastic over a ten-year period, the length of time modeled here. The immediate effect of a change in agricultural or biofuel markets on petroleum product markets could be larger than their shares in overall petroleum markets alone suggest, and these effects might remain consequential even after ten years.

Results

We simulate the petroleum and petroleum product model with varying assumptions about the relevant agricultural and biofuel variables (Table 1). Initial values for relevant agricultural commodity and biofuel variables are taken from the FAPRI-MU baseline[3]. Greater agricultural output, either of crops or of livestock products, has small initial price effects that diminish as petroleum supply and demand gradually adjust. For example, if production of corn, wheat, soybeans, rice, and cotton were 10% greater in the next ten years, then the initial impact would be slightly higher petroleum product prices, leading refiners to bid the petroleum price higher as well. Given time to adjust, the world production would rise, domestic refining capacity would expand slightly, and foreign fuel use would decline. Agriculture is a larger share of diesel markets than gasoline markets. The somewhat greater impact on diesel markets would dominate, leading these prices to remain higher for a longer period. The additional supplies of petroleum in response to the higher price means more refining and more production of gasoline as well as diesel. The additional gasoline refined would satisfy the increase in crop demand for this fuel, so the gasoline price effect would vanish.

A 10% increase in biofuels means that the already growing biofuel supplies rise that much faster, displacing petroleum products in transportation fuel use. As compared to biodiesel, ethanol use is a larger share of its fuel market and grows more quickly. Thus, the 10% increase in all years shocks the gasoline market more than the biodiesel market. When production of these crops and livestock products are increased as well as biofuels, the biofuel effects account for most of changes in fuel markets.

The implication of 1 billion bushels more of corn, wheat, or soybean production in all years is greater demand for gasoline and diesel fuels. As before, the small share of the overall markets for these fuels leads to small impacts from these changes. Even in the first year, the changes are modest and they nearly vanish after 10 years. A billion gallons more ethanol or biodiesel, in contrast, have stronger immediate and 10-year effects on fuel markets. A billion gallons more

[3] The production of crops or biofuels are not linked to one another in this exercise. In practice, an increase of one might lead to, or even be caused by, the increase in the other. We treat them independently to identify the impact of greater agricultural output for its ability to increase energy demand on the one hand and, on the other hand, greater biofuel output for its ability to reduce petroleum product demand.

ethanol pushes down competing gasoline price by $0.07, or 2.8%. The reduced refinery returns means less throughput of petroleum, so the diesel supply contracts somewhat and the diesel price rises slightly. The lower petroleum price eventually brings about some reduction in petroleum supply which, along with other adjustments in US and world demands, moderates the impacts. Although these responses are still developing even after 10 years, the fuel price effects are less than half as large as the initial impact. The effects of one billion gallons of additional biodiesel are similar, with the percent change in price halved going from the initial effect to the final effect. Biofuel effects again dominate the impacts if all of these shocks are imposed at the same time.

Table 1. Agricultural commodity and biofuel effects on petroleum markets.

	Immediate effects on US prices						Effects on US prices after 10 years					
	Gasoline		Diesel		Petroleum		Gasoline		Diesel		Petroleum	
	$/gallon	percent	$/gallon	percent	$/barrel	percent	$/gallon	percent	$/gallon	percent	$/barrel	percent
Proportional change: +10%												
Five crops*	0.001	0.1%	0.006	0.2%	0.06	0.1%	-0.001	0.0%	0.004	0.1%	0.02	0.0%
Meat and dairy*	0.003	0.1%	0.005	0.2%	0.06	0.1%	0.000	0.0%	0.003	0.1%	0.02	0.0%
Biofuels*	-0.078	-3.0%	0.000	0.0%	-0.37	-0.5%	-0.059	-1.4%	0.007	0.1%	-0.38	-0.3%
All of the above	-0.074	-2.9%	0.011	0.4%	-0.25	-0.3%	-0.061	-1.4%	0.013	0.3%	-0.34	-0.3%
Fixed change: +1 billion bushels or gallons												
Corn	0.001	0.0%	0.003	0.1%	0.03	0.0%	0.000	0.0%	0.001	0.0%	0.01	0.0%
Wheat	0.001	0.1%	0.004	0.2%	0.05	0.1%	-0.001	0.0%	0.002	0.0%	0.01	0.0%
Soybeans	0.001	0.0%	0.003	0.1%	0.03	0.0%	0.000	0.0%	0.002	0.0%	0.01	0.0%
Ethanol	-0.072	-2.8%	0.002	0.1%	-0.32	-0.4%	-0.022	-0.5%	0.009	0.2%	-0.13	-0.1%
Biodiesel	0.003	0.1%	-0.065	-2.3%	-0.57	-0.8%	0.017	0.4%	-0.059	-1.2%	-0.30	-0.3%
All of the above	-0.066	-2.5%	-0.053	-1.9%	-0.79	-1.1%	-0.006	-0.1%	-0.045	-0.9%	-0.40	-0.3%

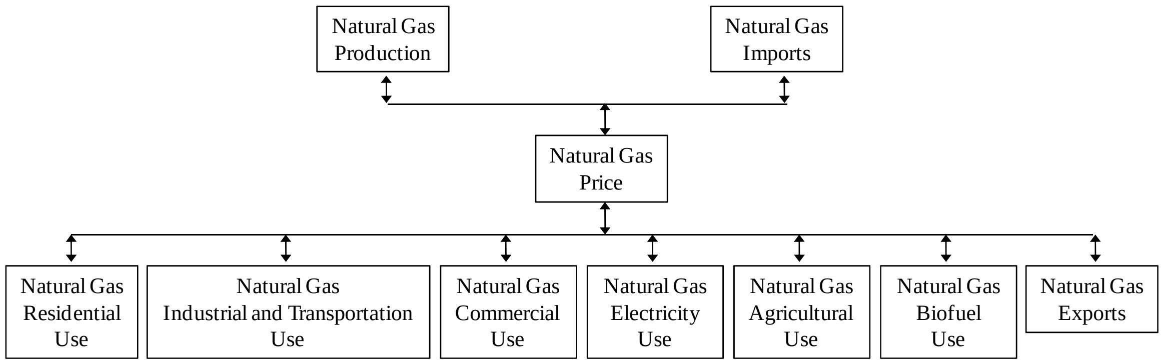
* Five crops are corn, soybeans, wheat, rice, and cotton; livestock products are beef, pork, chicken, turkey, and milk; and biofuels are ethanol and diesel.

Note: gasoline and diesel prices are retail prices for transportation uses, including taxes.

I.b. Agriculture and biofuel effects on natural gas markets

The US natural gas market representation does not link to an explicit ROW model, as in the case of petroleum and petroleum product markets, but the market for natural gas is much less global due to high transportation costs. Otherwise, the two models have certain similarities. The model is summarized as follows (Figure 2). Production and imports depend on domestic prices. Natural gas demand is disaggregated into various uses, including separate demands for corn dry mills producing ethanol and fertilizer production to be applied on area planted to corn and other crops.

Figure 2. Flowchart of US natural gas model.



EIA data are used to represent US natural gas prices and quantities. Imports are adjusted to be the sum of natural gas imports plus natural gas imports converted into natural gas equivalent.

Results

Published results from this representation of natural gas markets lead to certain conclusions about how agricultural and biofuel policies affect the natural gas market. Both start from FAPRI-MU estimates of agricultural and biofuel market effects in the event that certain biofuel policies are eliminated. For example, if biofuel use mandates, ethanol tariff, and the blender subsidy were discontinued, then FAPRI-MU estimated the average effects on production over 500 simulations as 36% less ethanol, 7% less corn, 4% more soybeans, and less than 1% more wheat and cotton.[4] Results from the natural gas model indicate that the consequences of lower natural gas demand due to these agricultural and biofuel market impacts include a 0.5% reduction in the wellhead price, 1.4% less production, 0.2% fewer imports, and expansion of 0.1-0.2% in other domestic demands.[5] By pulling randomly from the distribution of errors of the natural gas equations as well as taking each of the 500 simulation results from FAPRI-MU, natural gas model simulations span a range of possibilities, generating 500 different medium-term projections. This exercise supports the earlier findings in terms of the order of magnitude of the impact of an elimination of US biofuel policies on natural gas price, but also notes that the removal of the biofuel use mandates leads to greater variability in the demand for natural gas as an input into biofuels and slightly greater variability in demand for natural gas for corn production, but a very small impact on the natural gas price.[6]

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[4] See Meyer, Westhoff, and Thompson, "Impacts of selected US ethanol policy options" FAPRI-MU Report #04-09, 2009.

[5] See Whistance and Thompson, "How does increased corn-ethanol production affect US natural gas prices?" *Energy Policy* 38: 2315-2325, 2010.

[6] See Whistance, Thompson, and Meyer, "Ethanol policy effects on US natural gas prices and quantities," *American Economic Review* 100: 178–182, 2010.

Here, we explore the effects of selected shocks to the planted area for the specified crops and biofuel production from corn mills (Table 2). A 10% increase in these variables causes less than half a percent increase in the wellhead price of natural gas. The combined effect of the proportional change in the area planted to these crops has a greater impact on the price of natural gas than the ethanol production increase. Even combined, however, the total effect on the wellhead price is less than three cents. Given time for supplies and demands to adjust, these price effects diminish after 10 years. However, because of the increasing volumes of biofuels, the proportional change in ethanol implies a larger effect in later years, so the impact on the natural gas price in later years does not fall as dramatically from the immediate effect as in the case of more stable crop area planted. The ten-year price effects are less than a penny.

Increases of 10 million acres planted to corn causes an increase of $0.011, or 0.2%, in the wellhead natural gas price. These are very small changes in the natural gas market considering that 10 million acres represents a large change in corn area. Similar increases in wheat or soybean area imply less of an increase in fertilizer use and consequently a smaller impact on the natural gas price. A 1 billion gallon increase in ethanol production increases the natural gas price by $0.009, or 0.2%. After ten years, supply and demand adjustments reduce the price impacts by almost four-fifths relative to the immediate effect.

Table 2. Agricultural commodity and ethanol effects on natural gas.

	Effect on US wellhead price			
	Immediate		After 10 years	
	$/thou cu.ft.	percent	$/thou cu.ft.	percent
Proportional change: +10%				
Four crops*	0.015	0.3%	0.003	0.1%
Ethanol	0.010	0.2%	0.004	0.1%
All of the above	0.025	0.4%	0.007	0.1%
Fixed change: +10 million acres or 1 billion gallons				
Corn	0.011	0.2%	0.002	0.0%
Wheat	0.005	0.1%	0.001	0.0%
Soybeans	0.003	0.0%	0.001	0.0%
Ethanol	0.009	0.2%	0.002	0.0%
All of the above	0.028	0.5%	0.006	0.1%

* Four crops are corn, soybeans, wheat, and cotton.

I.c. Uncertainties and omitted effects

Our representation of energy markets focuses on the US. In the case of petroleum and petroleum product markets, our model is global. However, we do not estimate how that changes in biofuel and agricultural markets outside the US affect petroleum and petroleum product markets. For natural gas, the focus is exclusively on the US market, but the difficulty of trading natural gas could be overcome by changing volumes of liquefied natural gas, for example, if the price differences are large enough and, in any case, it might not be appropriate to separate the US from other North American markets.

Our research on petroleum and petroleum product markets exposes uncertainty about how producers and consumers respond to price changes, particularly for international supply and demand. In these cases, our elasticities are almost entirely chosen based on a literature review. Worse, many studies of demand tend to focus on aggregate petroleum or on one product, gasoline or diesel, and are consequently less useful as an input into our work.

An example that demonstrates the range of uncertainty and its implications for our results most clearly is the size and speed of world petroleum supply response to changes in prices. The literature suggests that short-run response is quite small. Krichene (2002) estimates a short-run own-price elasticity of petroleum supply of -0.07 or 0.01, depending on estimation method, and a long-run elasticity of 0.10.[7] Ramcharran (2002) disaggregates supply into OPEC and non-OPEC components and also finds mixed short-run own-price elasticities, estimating -0.17 for OPEC and 0.11 for non-OPEC.[8] Hochman et al. (2010) also find that quantity and price implications of assumed changes in biofuel quantities depend on market elasticities, and in particular on the potential for non-competitive behavior.[9] Based on estimation over historical data, US petroleum production rises by about 1% after 10 years if the price increases by 1%. A literature review suggests that a 1% increase in the petroleum price leads to a smaller global impact, and we assume an eventual increase of 0.35% production in the rest of world. Petroleum supply elasticities are a key point of uncertainty even before considering increasingly difficult questions such as whether or not the scale of response is constant (regardless of the price level or the size of the change) and whether our results spanning a 10-year go far enough into the future to capture the full effect.[10]

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[7] Krichene, N., 2002, "World crude oil and natural gas: a demand and supply model" *Energy Economics* 24, 557-576.

[8] Ramcharran, H., 2002, "Oil production responses to price changes: an empirical application of the competitive model to OPEC and non-OPEC countries" *Energy Economics* 24, 97-106.

[9] Hochman, G., D. Rajagopal, and D. Zilberman, 2010, "Are Biofuels the Culprit? OPEC, Food, and Fuel" *American Economic Review* 100, 183–187.

[10] Petroleum product demands are also uncertain. However, we find more studies reporting estimated demand elasticities, albeit typically for a single product and sometimes for a particular country, and we benefit from two surveys of the literature: Dahl, C., and Sterner, T., 1991, "Analyzing gasoline demand elasticities: a survey" *Energy Economics* 13, 203–210; and Graham, D., Glaister, S., 2002, "The demand for automobile fuel: a survey of elasticities" *Journal of Transportation Economics and Policy* 36, 1-25.

II. Energy price effects on agricultural and biofuel sectors

The effects of energy markets on agricultural and biofuel markets is assessed in this section by examining output of a structural economic model over the medium-term future using the 2010 FAPRI stochastic baseline. The FAPRI-MU stochastic models link key agricultural commodity and biofuel markets (Figure 3). Natural gas and petroleum prices feed into these models. Both of these energy prices, for example, affect costs of agricultural commodity production through their impacts on diesel and fertilizer prices. (This link is explored further in the next section.) Higher energy prices mean higher costs of crop and livestock production, leading to a reduction in quantities supplied and a reallocation away from less energy intensive commodities towards competing activities that use fewer inputs made from natural gas and petroleum.

Petroleum prices are critical to biofuel markets. Biofuels are substitutes for petroleum-based gasoline and diesel.[11] High prices for petroleum and petroleum products means a high demand for biofuels and low prices for petroleum and petroleum products cause a low demand for biofuels. The model also captures key cross-effects that follow from changes in energy prices. If a high energy price leads to more biofuels produced in the US from corn, then the distillers grains co-produced with that ethanol also rise, competing with crop products in the livestock feed mix.

Energy prices also play a part in determining consumer prices. Some of the effect is direct. A high petroleum price corresponds to high transportation and processing costs, increasing the margins between consumer and farm prices. There are also indirect effects. If energy prices are high, then the reduction in supply caused by higher costs of production and the increase in competing biofuel demands will tend to push consumer food prices higher.[12]

The FAPRI-MU stochastic model also includes certain policies that may have the power to sever some of these links from energy prices to agricultural and biofuel markets. The Energy Independence and Security Act (EISA) of 2007 amended the biofuel use mandates, or Renewable Fuel Standard (RFS2, to distinguish it from an earlier version). Four mandates require at least certain volumes of different types of biofuels are used in each year.[13] The share

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[11] A share of ethanol use is as an additive to gasoline to change certain properties, but current total ethanol consumption surpasses additive use. We expect that the relationship between the gasoline and ethanol is driven by substitution between these two fuels because any additional unit of ethanol must compete to displace gasoline.

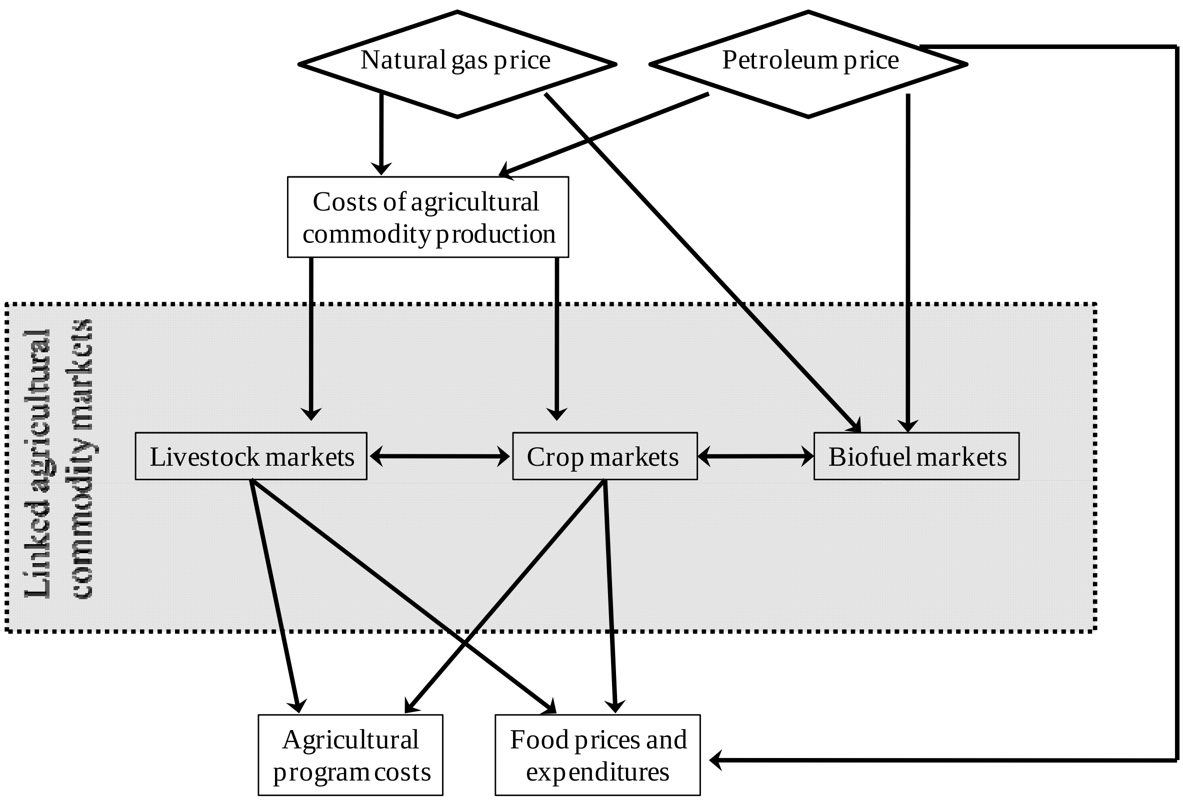
[12] A subsequent section addresses new work about the impacts of energy prices on costs of production.

[13] Descriptions of the biofuel use mandates are available in Thompson, Meyer, and Westhoff, "The New Markets for Renewable Identification Numbers" *Applied Economic Perspectives and Policy*, 32(4): 588-603. 2010; and Thompson, Meyer, and Westhoff, "Renewable Identification Numbers Are the Tracking Instrument and Bellwether of US Biofuel Mandates" *Eurochoices* 8 (3): 43-50, 2009.

that corn-starch ethanol can contribute to the total is capped at 15 billion gallons, under current law, with greater mandate growth in the future to be filled by advanced ethanol such as sugar-cane ethanol and cellulosic biofuels. If a mandate is not binding, then it has no direct impact on the markets. If a mandate is binding, then use of the biofuels that meet that mandate cannot be reduced and, moreover, might not rise for small price changes. A binding mandate can affect some of the impacts of energy price movements on biofuel quantities, severing or at least altering some of the links identified above.

The other key US biofuel policies are tax credits and ethanol tariffs. Tax credits are provided for the blending of biofuels, effectively encouraging more volumes to go into the motor fuel market, or in the case of cellulosic biofuel, to directly encourage production. The ethanol tariff is comprised of two parts: an ad valorem tariff and a larger specific tariff. While a small share of imports from some Caribbean sources are not assessed the specific tariff, most imports, including sugar-cane ethanol imports from Brazil, are.

Figure 3. Estimating effects of energy prices on agriculture and biofuel sectors.



The FAPRI-MU model is used for stochastic simulations.[14] A selection of key determining factors is drawn at random. Taking into account historical distributions and correlations, we draw 500 random paths for such key drivers as energy prices, weather-induced yield shocks, and demand shocks.[15] The model is solved for each of these 500 randomly determined paths for key drivers, generating as output 500 different outlooks for agricultural and biofuel markets for the medium-term future. Each set of output data represents a story, so to speak, with its own energy prices and shocks to yields and demands. These shocks work through markets to cause a consistent set of prices and quantities in crop, livestock, and biofuel markets, as well as government and consumer costs. Each set of output is also consistent with the policies in place, such as the biofuel use mandates.

Here, we explore the relationships between randomly drawn energy prices and key indicators of agricultural and biofuel markets in the US. We do so by testing the correlation and causality between these key indicators.[16]

II.a. Correlation among key indicators

Correlation among key indicators summarizes how they are related over the next ten years. We use an annual model, so the relationships are among annual average prices or total quantities, not monthly, weekly, or daily relationships. Nevertheless, by using the data from stochastic simulations as an input, the results cover a range of possible market settings.

Correlation statistics between ten-year averages of these variables relate them to one another (Table 3). The ten-year average correlation statistics tell us whether any particular two market indicators tend move in relation to each other over the period. These statistics give broad statements about whether two variables over a number of years will tend (a) both to be high or low at the same time, (b) to go in opposite directions, with one high when the other is low or vice versa, or (c) have no relationship with one another. These numbers tend to show the longer-term or sustained relationships among key indicators.

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[14] The model is described in FAPRI-MU, "Documentation of the FAPRI Modeling System," FAPRI-MU Report #12-04, 2004; and Meyer and Thompson, "FAPRI-MU US Biofuels, Corn Processing, Distillers Grains, Fats, Switchgrass, and Corn Stover Model Documentation," FAPRI-MU Report #09-10, 2010.

[15] Historical data are used to derive correlation statistics among energy prices, such as the prices for petroleum, petroleum products, and natural gas. In the exercises reported here, these relationships are somewhat attenuated in some cases. For example, marketing year average energy prices that are relevant for crop markets are compared to calendar year energy price data that are relevant for livestock markets.

[16] This chapter expands on methods introduced in Thompson, Meyer, and Westhoff, "How Does Petroleum Price and Corn Yield Volatility Affect Ethanol Markets with and without an Ethanol Use Mandate?" *Energy Policy* 37(2): 745-749, 2009.

Each entry in this table reduces a set of such complicated interactions to a single number. As such, they hide any number of results with mostly binding mandates or with mostly non-binding mandates, good weather conditions for crop production or bad, ethanol use expanding as rapidly as possible and biofuel use languishing, and so on. We highlight a selection of these results, focusing on the correlation between biofuel and agricultural sector indicators and energy prices (left-hand columns).

Table 3 indicates that the long-run relationship between oil price and the implied retail ethanol price is 0.97.[17] This result suggests that higher petroleum and retail ethanol price will both tend to be high or low over any multi-year period of time. This follows logically: a high petroleum price means more demand for ethanol as a substitute for gasoline, and consequently a higher ethanol price. Even this basic result hides many complicating factors. First, the degree to which an increase in ethanol demand is reflected in a change in price, as opposed to a change in quantity, depends on supply and demand elasticities. If ethanol expansion into fuels with a high proportion of ethanol is largely unconstrained over a ten-year period of time despite technical complications, then the quantity of ethanol is likely to expand rapidly. Conversely, if lower oil price leads to weak demand for ethanol that cannot result in lower quantities because of biofuel use mandates, then the full effect of weak demand falls on the retail ethanol price. (See box titled "Mandate Economics".) Second, numerous other factors come into play, including mandate compliance costs and, given time to adjust, cellulosic and other biofuel production capacity.

[17] The implied ethanol retail prices is calculated as the consumer's willingness to pay for the given volume of ethanol supplied and is influenced by quantities relative to the size of E10 and E85 markets.

Mandate Economics

Our understanding of the role of biofuel use mandates in biofuel markets is illustrated here. The left-hand diagram shows the case that the mandate requires a greater volume of use than would otherwise be used. In that case, blenders must increase the amount of biofuels they buy and sell. By meeting the mandate, blenders drive the price of biofuels they buy higher and push down the prices consumers pay for biofuels (implicit in blended fuels, such as E10). The price gap determines the value of Renewable Identification Numbers (RINs) that blenders submit to show compliance. A non-binding mandate is shown at right for reference, to show that the producer and consumer prices would be the same, after taking into account normal margins, if the mandate is below the amount traded in the market at prevailing prices.

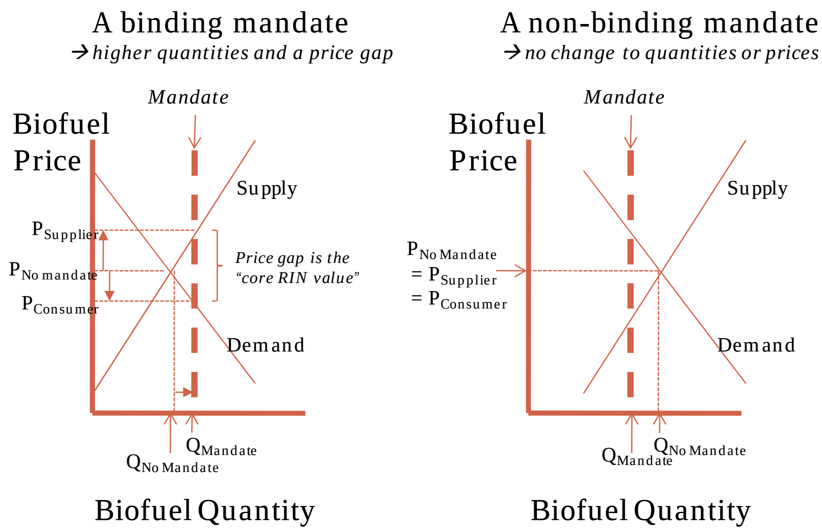

Figure from Thompson, Meyer, and Westhoff, "Renewable Identification Numbers (RINs) Are the Bellwether of US Biofuel Mandates" Eurochoices 8 (3): 43-50, 2009.

Changes in the petroleum price change the demand for biofuels, but that might or might not affect biofuel quantities. A higher petroleum price shifts out the demand for biofuels. However, if the biofuel mandate is binding (diagram at left), and remains binding, then the increased demand does not translate to an increase in the quantity of biofuels used and produced. There is no reason for more agricultural feedstocks to go into biofuel production given that the quantities in the market do not change. On the other hand, if the petroleum price increases and the mandate is not binding (diagram at right) or becomes non-binding, then the quantity of biofuel used and produced increases as well. In the case of a non-binding mandate, then, the higher petroleum price will lead to greater biofuel feedstock purchases.

Data in Table 3 also show that the oil price is slightly less correlated with the wholesale or rack price for corn-starch ethanol, 0.91, than the retail price, 0.97. The correlation between these two ethanol prices is high, 0.94. These data suggest that the portion of the mandate that applies to this type of biofuel is usually not binding, so there is typically no wedge driven between the rack corn-starch and retail ethanol prices. If the mandate is binding, then the blenders would be required to buy and sell ethanol even if they pay a higher price to buy it than the price they get when they sell it for retail use.

The correlation statistics for biodiesel prices suggest that there is a wedge between these prices more often than is the case for ethanol. A comparison of biodiesel retail and rack prices reveals that the relationship is strong, 0.80, and both are also strongly correlated with petroleum, 0.96 for retail and 0.80 for rack. But the retail and rack biodiesel prices move differently sometimes. These correlation statistics indicate that mandates drive retail and rack biodiesel prices apart in at least some years of the 10-year period.

The negative correlation between cellulosic ethanol price and petroleum price is purely a result of the legislation that creates the cellulosic biofuel use mandate and our assumption about how it will be implemented. We assume that this mandate will be waived.[18] The EISA requires that a credit is offered for sale in the event of a waiver, and it sets out that this waiver credit will move in the opposite direction of the petroleum price.[19] This credit is then bid into the wholesale or rack price of cellulosic ethanol, along with other factors such as the retail value of the fuel itself, leading to a small but noteworthy negative correlation between the cellulosic ethanol price and the petroleum price.

All crop prices shown are positively correlated with the petroleum price, with values of 0.37 for soybeans, 0.38 for wheat, and 0.54 for corn, over ten-year period averages. Judging from the data representing correlation statistics for the area planted to each of these crops and other variables, a higher petroleum price drives up demand for corn to use for biofuel production, drawing more land into this crop, and increasing cropland area overall. The higher petroleum price also diverts corn from other uses, such as for feed, leading to higher livestock product prices at least if sustained over a ten-year period. The soybean oil price suggests strong effects of a high oil price through both the increase in demand for biodiesel and, probably more importantly, the decrease in supply as land is shifted from corn to soybeans. The correlation between petroleum and distillers grain prices based on 10-year averages suggests a sort of balance among the competing forces of greater supply as ethanol production expands, with land reallocated away from soybeans and fewer animals to feed.

Petroleum prices are inversely correlated with biofuel mandate compliance costs and positively correlated with consumer food prices and expenditures. Higher petroleum prices increase crop production costs and draw crop and crop products into biofuel production, away from food and feed uses. In addition, the higher petroleum price increases the margins between farm-gate

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[18] The cellulosic biofuel mandate has been waived in both 2010 and in 2011.

[19] The credit price per gallon is the higher of $0.25 or $3.00 less the average unleaded gasoline price, with both triggers adjusted for inflation.

prices and final retail prices that are necessary to pay for transportation, processing, packaging, and other energy-intensive processes. All these impacts point in the same direction: a higher petroleum price means higher consumer food prices, which is reflected here by a correlation coefficient of 0.52. Although the quantities of domestic food use decrease slightly with a general increase in food prices, total food demand is very inelastic in the U.S. and the correlation between petroleum and food expenditures is about the same, at 0.52. A high petroleum price also makes it easier to meet the mandates and could make each one non-binding at some point, but a low petroleum price makes it harder to meet the mandated minimum levels of biofuel use. This effect is reflected in correlation statistics between petroleum price and mandate compliance costs of -0.71 to -0.73 over a 10-year period.

Table 3. Correlations among variables 2011/12-2019/20 average.

	Oil price$_t$	Natural gas	Ethanol price (retail eqv.)	Ethanol price (rack)	Cellulosic ethanol price (rack)	Biodiesel price (retail eqv.)	Biodiesel price (rack)	Corn farm price	Soybean farm price	Wheat price	Soybean oil price	Distillers grains price (DDGS)	Ethanol production	Ethanol use	Ethanol net-imports	Biodiesel production	Biodiesel use	Biodiesel net exports	Corn area planted	Soybean area planted	Wheat area planted	Total crop area planted*
Oil price$_t$	1.00	0.37	0.97	0.91	-0.28	0.96	0.80	0.54	0.37	0.38	0.76	0.07	0.84	0.82	-0.55	0.70	0.77	0.08	0.47	-0.34	-0.06	0.23
Natural gas	0.37	1.00	0.44	0.48	-0.12	0.41	0.23	0.14	0.04	0.12	0.17	0.01	0.28	0.27	-0.25	0.42	0.42	0.18	0.01	0.02	-0.16	-0.08
Ethanol price (retail eqv.)	0.97	0.44	1.00	0.94	-0.32	0.99	0.79	0.57	0.39	0.42	0.75	0.12	0.81	0.80	-0.49	0.67	0.75	0.04	0.47	-0.32	-0.06	0.26
Ethanol price (rack)	0.91	0.48	0.94	1.00	-0.12	0.91	0.81	0.66	0.47	0.50	0.78	0.22	0.80	0.79	-0.41	0.65	0.76	-0.07	0.51	-0.36	-0.02	0.27
Cellulosic ethanol price (rack)	-0.28	-0.12	-0.32	-0.12	1.00	-0.37	-0.17	-0.06	-0.01	-0.07	-0.14	0.00	-0.07	-0.05	0.25	-0.10	-0.07	-0.15	-0.13	0.09	-0.08	-0.24
Biodiesel price (retail eqv.)	0.96	0.41	0.99	0.91	-0.37	1.00	0.80	0.57	0.41	0.42	0.77	0.12	0.82	0.81	-0.44	0.61	0.69	0.01	0.50	-0.34	-0.05	0.29
Biodiesel price (rack)	0.80	0.23	0.79	0.81	-0.17	0.80	1.00	0.65	0.58	0.54	0.95	0.27	0.69	0.69	-0.23	0.34	0.49	-0.36	0.64	-0.32	0.14	0.46
Corn farm price	0.54	0.14	0.57	0.66	-0.06	0.57	0.65	1.00	0.83	0.89	0.69	0.82	0.41	0.44	0.14	0.07	0.18	-0.37	0.73	-0.45	0.25	0.61
Soybean farm price	0.37	0.04	0.39	0.47	-0.01	0.41	0.58	0.83	1.00	0.77	0.68	0.81	0.25	0.29	0.26	-0.13	0.00	-0.50	0.66	-0.29	0.31	0.65
Wheat price	0.38	0.12	0.42	0.50	-0.07	0.42	0.54	0.89	0.77	1.00	0.56	0.81	0.24	0.27	0.19	-0.01	0.08	-0.35	0.75	-0.48	0.50	0.71
Soybean oil price	0.76	0.17	0.75	0.78	-0.14	0.77	0.95	0.69	0.68	0.56	1.00	0.34	0.64	0.65	-0.14	0.22	0.39	-0.47	0.61	-0.34	0.12	0.45
Distillers grains price (DDGS)	0.07	0.01	0.12	0.22	0.00	0.12	0.27	0.82	0.81	0.81	0.34	1.00	-0.11	-0.08	0.38	-0.28	-0.21	-0.39	0.52	-0.25	0.38	0.59
Ethanol production	0.84	0.28	0.81	0.80	-0.07	0.82	0.69	0.41	0.25	0.24	0.64	-0.11	1.00	1.00	-0.40	0.63	0.70	0.04	0.43	-0.34	-0.16	0.12
Corn-starch ethanol production	0.88	0.27	0.87	0.81	-0.27	0.89	0.73	0.44	0.28	0.28	0.67	-0.08	0.97	0.96	-0.43	0.62	0.69	0.05	0.47	-0.36	-0.11	0.21
Cellulosic ethanol production	-0.24	0.00	-0.31	-0.12	0.81	-0.34	-0.19	-0.12	-0.10	-0.13	-0.17	-0.10	0.05	0.06	0.18	-0.03	-0.02	-0.04	-0.19	0.09	-0.16	-0.35
Ethanol use	0.82	0.27	0.80	0.79	-0.05	0.81	0.69	0.44	0.29	0.27	0.65	-0.08	1.00	1.00	-0.32	0.58	0.65	0.00	0.45	-0.35	-0.15	0.14
E85 Ethanol use	0.88	0.34	0.87	0.83	-0.16	0.89	0.75	0.51	0.34	0.34	0.69	-0.01	0.98	0.98	-0.35	0.60	0.67	0.02	0.51	-0.37	-0.11	0.22
Ethanol net-imports	-0.55	-0.25	-0.49	-0.41	0.25	-0.44	-0.23	0.14	0.26	0.19	-0.14	0.38	-0.40	-0.32	1.00	-0.82	-0.79	-0.49	0.10	0.00	0.22	0.23
Biodiesel production	0.70	0.42	0.67	0.65	-0.10	0.61	0.34	0.07	-0.13	-0.01	0.22	-0.28	0.63	0.58	-0.82	1.00	0.97	0.57	0.05	-0.12	-0.19	-0.19
Biodiesel use	0.77	0.42	0.75	0.76	-0.07	0.69	0.49	0.18	0.00	0.08	0.39	-0.21	0.70	0.65	-0.79	0.97	1.00	0.37	0.14	-0.16	-0.17	-0.11
Biodiesel net exports	0.08	0.18	0.04	-0.07	-0.15	0.01	-0.36	-0.37	-0.50	-0.35	-0.47	-0.39	0.04	0.00	-0.49	0.57	0.37	1.00	-0.32	0.09	-0.19	-0.35
Corn area planted	0.47	0.01	0.47	0.51	-0.13	0.50	0.64	0.73	0.66	0.75	0.61	0.52	0.43	0.45	0.10	0.05	0.14	-0.32	1.00	-0.76	0.45	0.78
Soybean area planted	-0.34	0.02	-0.32	-0.36	0.09	-0.34	-0.32	-0.45	-0.29	-0.48	-0.34	-0.25	-0.34	-0.35	0.00	-0.12	-0.16	0.09	-0.76	1.00	-0.36	-0.42
Wheat area planted	-0.06	-0.16	-0.06	-0.02	-0.08	-0.05	0.14	0.25	0.31	0.50	0.12	0.38	-0.16	-0.15	0.22	-0.19	-0.17	-0.19	0.45	-0.36	1.00	0.54
Total crop area planted*	0.23	-0.08	0.26	0.27	-0.24	0.29	0.46	0.61	0.65	0.71	0.45	0.59	0.12	0.14	0.23	-0.19	-0.11	-0.35	0.78	-0.42	0.54	1.00
Corn cost of production	0.23	0.36	0.26	0.29	-0.07	0.24	0.12	0.27	0.04	0.18	0.10	0.19	0.13	0.13	-0.11	0.24	0.24	0.09	-0.17	0.12	-0.20	-0.30
Soybeans cost of production	0.30	0.25	0.33	0.33	-0.11	0.31	0.20	0.28	0.09	0.19	0.19	0.15	0.21	0.20	-0.14	0.26	0.28	0.07	-0.11	0.05	-0.15	-0.25
Corn production	0.50	0.09	0.49	0.45	-0.21	0.52	0.54	0.33	0.31	0.42	0.50	0.06	0.52	0.53	-0.13	0.23	0.30	-0.12	0.65	-0.45	0.29	0.42
Corn use for ethanol	0.88	0.27	0.87	0.81	-0.27	0.89	0.73	0.44	0.28	0.28	0.67	-0.08	0.97	0.96	-0.43	0.62	0.68	0.05	0.47	-0.36	-0.11	0.21
Corn use for feed	-0.72	-0.21	-0.73	-0.72	0.14	-0.73	-0.62	-0.53	-0.29	-0.29	-0.60	-0.09	-0.74	-0.73	0.29	-0.46	-0.53	0.04	-0.34	0.27	0.16	-0.14
Corn exports	-0.24	-0.17	-0.22	-0.18	0.05	-0.21	-0.02	0.13	0.20	0.36	0.01	0.30	-0.34	-0.32	0.32	-0.36	-0.33	-0.26	0.33	-0.21	0.50	0.31
Corn ending stocks	-0.22	-0.04	-0.25	-0.30	0.04	-0.25	-0.32	-0.61	-0.50	-0.56	-0.36	-0.55	-0.13	-0.15	-0.18	0.08	0.01	0.27	-0.43	0.24	-0.20	-0.48
Ethanol mandate(s) compliance cost	-0.71	-0.22	-0.77	-0.51	0.67	-0.78	-0.48	-0.22	-0.13	-0.12	-0.45	0.08	-0.49	-0.46	0.50	-0.48	-0.49	-0.21	-0.22	0.15	0.10	-0.17
Biodiesel mandate compliance cost	-0.73	-0.42	-0.80	-0.64	0.45	-0.82	-0.38	-0.34	-0.13	-0.22	-0.32	0.02	-0.65	-0.64	0.33	-0.52	-0.50	-0.31	-0.28	0.24	0.16	-0.14
Total mandate(s) compliance cost	-0.73	-0.24	-0.78	-0.53	0.66	-0.80	-0.48	-0.24	-0.13	-0.13	-0.44	0.08	-0.52	-0.49	0.49	-0.50	-0.50	-0.23	-0.23	0.16	0.10	-0.17
Consumer food price index	0.52	0.41	0.55	0.53	-0.24	0.55	0.44	0.36	0.22	0.28	0.41	0.13	0.41	0.40	-0.25	0.37	0.41	0.04	0.22	-0.17	-0.02	0.03
Consumer food expenditures	0.52	0.41	0.55	0.53	-0.23	0.55	0.44	0.35	0.22	0.27	0.41	0.12	0.41	0.40	-0.25	0.37	0.41	0.04	0.21	-0.16	-0.03	0.03
Beef cattle price	0.10	0.03	0.10	0.10	-0.10	0.10	0.16	0.21	0.19	0.22	0.15	0.17	0.01	0.02	0.05	-0.03	-0.01	-0.08	0.18	-0.09	0.09	0.19
Hog price	0.22	0.10	0.23	0.25	-0.11	0.24	0.28	0.47	0.40	0.48	0.25	0.42	0.12	0.13	0.10	0.02	0.05	-0.10	0.42	-0.26	0.28	0.41
Wholesale chicken price	0.13	-0.04	0.15	0.18	-0.09	0.16	0.25	0.58	0.62	0.61	0.27	0.64	0.03	0.05	0.25	-0.16	-0.11	-0.26	0.50	-0.24	0.35	0.55
All milk price	0.11	0.11	0.14	0.18	-0.08	0.13	0.17	0.26	0.22	0.27	0.16	0.25	0.04	0.04	0.03	0.04	0.07	-0.09	0.21	-0.09	0.12	0.18

Natural gas prices are correlated with many of these indicators in the same way as the petroleum price over the 10-year period, but not as strongly. One reason is the simple fact that petroleum and natural gas prices tend to move similarly, as the correlation coefficient of 0.37 suggests.[20] Perhaps the most noteworthy comparison is in crop production costs. The correlation between natural gas and crop production costs is 0.36 for corn and 0.25 for soybeans, both of which are comparable to the correlation with petroleum. Natural gas plays an important part in these costs, suggesting that natural gas price changes by themselves could have a large effect on crop supplies as compared to more modest effects on demand.[21] Whereas natural gas drives costs of crop production primarily through its effect on the price of nitrogen fertilizers, which account for a larger share in production costs of corn than the legume soybeans, the correlation of petroleum price and soybean production costs is greater than the correlation of petroleum price and corn production costs because of the larger cost share of fuels in soybean production. Natural gas is inversely correlated with total crop area, but only slightly, -0.08. The effects are murky probably because petroleum and natural gas prices tend to move somewhat alike.

Correlation statistics for any given year represent the likelihood that any given pair of prices or quantities will tend to be high or low at the same time, that they will move in opposite direction, or that their changes will be appear to be independent of one another in that year. Here, we consider the case of 500 simulations for the 2011/12 marketing year, each representing a different context in terms of energy prices, yields, and other factors.

The three effects of petroleum prices – higher production costs, more demand for biofuels, and higher margins between consumer and producer prices (see Figure 3) – are not all manifested in one-year correlation statistics, even though all are present. First, the magnitude of these effects vary and are particularly sensitive to factors that determine whether or not the biofuel use mandates are binding.[22] In 2011/12, the elements of the mandates that are applicable to corn-

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[20] This indirect relationship highlights the fact that these correlation statistics simply tell us if things move alike, in opposite directions, or independently of one another. The causal relationships used here to explain these movements are based on inference and our understanding of how these markets work (as represented in the underlying models we built and maintain).

[21] Natural gas prices have other effects through their role in electricity prices, as discussed in the previous section, and on the costs of refining feedstocks into biofuels.

[22] Our representation of US biofuel mandates reflects some of the important determinants of their impact on within year, but not all. While we include mandate hierarchy, rollover, deficits, and waivers, under certain assumptions, not all relevant regulations are modeled. Our treatment of the biofuel mandates is described in three publications: Thompson, Meyer, and Westhoff (2010) "The New Markets for Renewable Identification Numbers" *Applied Economic Perspectives and Policy* 32(4): 588-603; Thompson, Meyer, and Westhoff (2010) "What to Conclude about Biofuel Mandates from Evolving Prices for

starch ethanol and biodiesel are growing. A second reason why the underlying links from petroleum price to agricultural and biofuel markets may be obscured is that there is not enough time for people to respond to price changes. For example, crop area cannot be reallocated in response to changes in the average petroleum price during the marketing year, after harvest. Biofuel production capacity is likewise constrained in the short run and may put an upward bound on short run production quantities.

Table 4 reveals that the petroleum price is correlated with the corn price at 0.09, ethanol rack price at 0.74, and the ethanol retail price at 0.82 in 2011/12, as compared to 0.54, 0.91, and 0.97 over the ten-year averages (shown in Table 3).[23] The lower correlation with the corn price and higher correlation with the retail ethanol price presumably reflect both the somewhat greater frequency of that corn-starch ethanol quantity cannot adjust because of a binding mandate. This latter point is particularly important, and is also apparent in the limited correlation between petroleum price and corn area in 2011/12, as compared to the 0.50 correlation between the ten-year average values for these same two variables.

Table 4 correlation statistics for biodiesel prices demonstrate the potential for the biodiesel mandate to create a price wedge, and its implications for inter-action among sectors. The petroleum price is correlated with the retail biodiesel price just as strongly as over the ten-year averages, 0.96 in either case. However, the 2011/12 correlation between petroleum and biodiesel rack price is only 0.22 as compared to 0.80 over the ten-year period. The primary reason for this difference is probably the very high incidence of a binding biodiesel mandate in 2011/12.[24] As this mandate often constrains the quantity of biodiesel use in the US, changes in the petroleum price that lead to changes in biodiesel demand can affect only the retail price; no quantity changes feed back to rack prices.[25] Because the link from petroleum to biodiesel rack price is severed in many simulations, the correlation between petroleum price and biodiesel production

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Renewable Identification Numbers?" *American Journal of Agricultural Economics*; and Meyer and Thompson (2010) "FAPRI-MU US Biofuels, Corn Processing, Distillers Grains, Fats, Switchgrass, and Corn Stover Model Documentation" FAPRI-MU #09-10.

[23] The lower correlation of E85 and the petroleum price in 2011/12 relative to the overall average suggests that the blend wall is more likely to play a role in the earliest year of the projections when few consumers have the wherewithal to buy high-blend fuels.

[24] This is the case even though the tax credit for biodiesel use is assumed to be extended throughout the entire baseline period. In fact, at the time of writing the biodiesel credit has not been extended beyond its January 1, 2012 expiration date, and its future is in debate.

[25] Given a large enough increase in the petroleum price, of course, the quantity of biodiesel demanded would eventually exceed the mandate.

is lower (0.49 in 2011/12 as compared to 0.70 over the ten-year averages), as is its correlation with the soybean oil price (0.26 versus 0.37).

Natural gas prices are also correlated with many of the key indicators we show, but less so, in 2011/12. While still positive, the strength of correlation of natural gas prices with corn, wheat, soybean oil and distillers grains all fall. This weakness reflects the fact that the primary impact of natural gas is on costs of crop and ethanol production, and it takes more than one marketing year for crop area to be reallocated or ethanol production capacity adjusted.

Some of the other correlation results in 2011/12 are not surprising. The corn price is positively correlated with energy and other crop prices, for example. However, the corn price is negatively correlated with ethanol production and use and positively correlated with ethanol imports in a single marketing year. The relationship between corn price and corn market quantities are even more telling, with a negative correlation between corn price and corn production. These results reflect short-run constraints on the supply side, in part, and also the importance of the variations in crop yields in the short-run. For example, a bad corn yield that decreases production from planted area will lead buyers to bid the corn price higher in the current marketing year.[26] Corn price and production are negatively correlated in the marketing year, even though producers can respond to the price signal by planting more corn for the next marketing year.

The correlation between corn prices and ethanol production is positive over the ten-year averages because, over time, the demand side plays a strong role and supply side has time to adjust. The correlation between corn price and corn production of the ten-year average statistic (0.33) reflects in large part the difference in results if time is allowed for acres to be shifted from one use to another.

The costs of complying with biofuel use mandates depends on how binding they are. If they are not binding, then these costs fall to close to zero. If the mandated volumes are difficult for blenders to meet because of high biofuel producer prices and low consumer demand, then the mandate compliance costs are high. In 2011/12, mandate compliance costs fall as petroleum prices rise, as we would expect. Compliance costs increase with the prices of crops that are common feedstocks to biofuel production.

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[26] How high the corn price rises in this case depends on demand response and there are some constraints that limit how quickly demand can change. If the number of livestock is slow to respond to higher feed costs, then corn feed might not decrease quickly even as price rises. If the biofuel mandates are binding, then ethanol refineries might be willing to buy a corresponding amount of corn even at a high price.

Table 4. Correlations among variables in 2011/12.

	Oil price$_t$	Natural gas	Ethanol price (retail eqv.)	Ethanol price (rack)	Cellulosic ethanol price (rack)	Biodiesel price (retail eqv.)	Biodiesel price (rack)	Corn farm price	Soybean farm price	Wheat price	Soybean oil price	Distillers grains price (DDGS)	Ethanol production	Ethanol use	Ethanol net-imports	Biodiesel production	Biodiesel use	Biodiesel net exports	Corn area planted	Soybean area planted	Wheat area planted	Total crop area planted*
Oil price$_t$	1.00	0.26	0.82	0.74	-0.71	0.96	0.22	0.09	0.12	0.03	0.26	0.01	0.72	0.78	0.13	0.49	0.56	0.13	0.01	-0.04	0.00	-0.08
Natural gas	0.26	1.00	0.40	0.40	-0.21	0.35	0.04	0.10	0.02	0.06	0.06	0.07	0.11	0.16	0.21	0.21	0.23	0.08	-0.09	0.05	-0.12	-0.20
Ethanol price (retail eqv.)	0.82	0.40	1.00	0.97	-0.36	0.85	0.22	0.51	0.29	0.28	0.37	0.40	0.38	0.51	0.48	0.34	0.43	-0.01	-0.16	0.06	0.01	-0.21
Ethanol price (rack)	0.74	0.40	0.97	1.00	-0.26	0.77	0.25	0.61	0.35	0.38	0.42	0.51	0.22	0.36	0.57	0.30	0.40	-0.07	-0.13	0.06	0.02	-0.16
Cellulosic ethanol price (rack)	-0.71	-0.21	-0.36	-0.26	1.00	-0.76	-0.15	0.26	0.04	0.15	-0.09	0.28	-0.77	-0.77	0.18	-0.35	-0.37	-0.16	-0.17	0.10	0.08	-0.05
Biodiesel price (retail eqv.)	0.96	0.35	0.85	0.77	-0.76	1.00	0.23	0.13	0.18	0.05	0.33	0.05	0.72	0.80	0.17	0.40	0.48	0.05	0.02	-0.07	-0.03	-0.12
Biodiesel price (rack)	0.22	0.04	0.22	0.25	-0.15	0.23	1.00	0.08	0.11	0.25	0.40	0.05	0.13	0.15	0.13	0.07	0.22	-0.29	0.28	0.19	-0.32	0.51
Corn farm price	0.09	0.10	0.51	0.61	0.26	0.13	0.08	1.00	0.60	0.68	0.44	0.96	-0.51	-0.39	0.62	-0.27	-0.21	-0.28	-0.15	0.09	0.10	-0.08
Soybean farm price	0.12	0.02	0.29	0.35	0.04	0.18	0.11	0.60	1.00	0.45	0.77	0.75	-0.22	-0.15	0.37	-0.52	-0.41	-0.52	0.29	-0.40	0.18	0.03
Wheat price	0.03	0.06	0.28	0.38	0.15	0.05	0.25	0.68	0.45	1.00	0.38	0.68	-0.39	-0.33	0.41	-0.21	-0.15	-0.26	0.27	-0.14	0.00	0.23
Soybean oil price	0.26	0.06	0.37	0.42	-0.09	0.33	0.40	0.44	0.77	0.38	1.00	0.49	-0.02	0.04	0.35	-0.46	-0.28	-0.66	0.26	-0.25	0.06	0.10
Distillers grains price (DDGS)	0.01	0.07	0.40	0.51	0.28	0.05	0.05	0.96	0.75	0.68	0.49	1.00	-0.55	-0.44	0.60	-0.37	-0.31	-0.33	-0.04	-0.04	0.14	-0.05
Ethanol production	0.72	0.11	0.38	0.22	-0.77	0.72	0.13	-0.51	-0.22	-0.39	-0.02	-0.55	1.00	0.98	-0.34	0.47	0.48	0.24	0.06	-0.10	-0.06	-0.09
Corn-starch ethanol production	0.71	0.10	0.36	0.20	-0.78	0.71	0.12	-0.51	-0.22	-0.38	-0.02	-0.55	1.00	0.98	-0.35	0.46	0.47	0.24	0.08	-0.11	-0.06	-0.07
Cellulosic ethanol production	-0.67	-0.20	-0.51	-0.47	0.76	-0.72	-0.41	-0.13	-0.27	-0.23	-0.37	-0.12	-0.45	-0.49	-0.13	-0.18	-0.25	0.06	-0.33	0.12	0.10	-0.29
Ethanol use	0.78	0.16	0.51	0.36	-0.77	0.80	0.15	-0.39	-0.15	-0.33	0.04	-0.44	0.98	1.00	-0.15	0.49	0.51	0.24	0.02	-0.09	-0.05	-0.14
E85 Ethanol use	0.82	0.26	0.70	0.65	-0.55	0.82	0.25	-0.09	0.00	-0.12	0.16	-0.16	0.74	0.81	0.16	0.49	0.55	0.15	0.00	-0.07	-0.05	-0.15
Ethanol net-imports	0.13	0.21	0.48	0.57	0.18	0.17	0.13	0.62	0.37	0.41	0.35	0.60	-0.34	-0.15	1.00	-0.02	0.03	-0.13	-0.10	0.06	0.01	-0.10
Biodiesel production	0.49	0.21	0.34	0.30	-0.35	0.40	0.07	-0.27	-0.52	-0.21	-0.46	-0.37	0.47	0.49	-0.02	1.00	0.94	0.69	-0.19	0.27	-0.11	-0.05
Biodiesel use	0.56	0.23	0.43	0.40	-0.37	0.48	0.22	-0.21	-0.41	-0.15	-0.28	-0.31	0.48	0.51	0.03	0.94	1.00	0.40	-0.13	0.27	-0.13	0.02
Biodiesel net exports	0.13	0.08	-0.01	-0.07	-0.16	0.05	-0.29	-0.28	-0.52	-0.26	-0.66	-0.33	0.24	0.24	-0.13	0.69	0.40	1.00	-0.24	0.16	-0.02	-0.17
Corn area planted	0.01	-0.09	-0.16	-0.13	-0.17	0.02	0.28	-0.15	0.29	0.27	0.26	-0.04	0.06	0.02	-0.10	-0.19	-0.13	-0.24	1.00	-0.72	-0.06	0.62
Soybean area planted	-0.04	0.05	0.06	0.06	0.10	-0.07	0.19	0.09	-0.40	-0.14	-0.25	-0.04	-0.10	-0.09	0.06	0.27	0.27	0.16	-0.72	1.00	-0.29	-0.01
Wheat area planted	0.00	-0.12	0.01	0.02	0.08	-0.03	-0.32	0.10	0.18	0.00	0.06	0.14	-0.06	-0.05	0.01	-0.11	-0.13	-0.02	-0.06	-0.29	1.00	-0.02
Total crop area planted*	-0.08	-0.20	-0.21	-0.16	-0.05	-0.12	0.51	-0.08	0.03	0.23	0.10	-0.05	-0.09	-0.14	-0.10	-0.05	0.02	-0.17	0.62	-0.01	-0.02	1.00
Corn cost of production	0.16	0.36	0.24	0.26	-0.10	0.19	0.02	0.20	0.08	0.14	0.09	0.17	-0.03	0.00	0.16	0.06	0.07	0.01	-0.08	0.01	-0.16	-0.30
Soybeans cost of production	0.26	0.23	0.30	0.30	-0.19	0.29	0.05	0.19	0.10	0.10	0.13	0.16	0.07	0.10	0.16	0.09	0.12	0.00	-0.05	-0.04	-0.10	-0.28
Corn production	0.11	-0.12	-0.23	-0.29	-0.34	0.08	0.17	-0.62	-0.28	-0.12	-0.09	-0.58	0.43	0.35	-0.39	0.14	0.16	0.05	0.50	-0.26	-0.12	0.40
Corn use for ethanol	0.71	0.10	0.36	0.20	-0.78	0.72	0.13	-0.51	-0.22	-0.38	-0.02	-0.55	1.00	0.98	-0.35	0.46	0.47	0.24	0.08	-0.11	-0.06	-0.07
Corn use for feed	-0.17	-0.16	-0.47	-0.51	-0.10	-0.19	0.00	-0.63	-0.10	-0.17	-0.08	-0.49	0.21	0.11	-0.39	-0.07	-0.07	-0.03	0.48	-0.38	-0.06	0.24
Corn exorts	-0.16	-0.11	-0.15	-0.12	0.11	-0.18	0.09	0.07	-0.05	0.40	-0.01	0.06	-0.20	-0.22	-0.02	-0.11	-0.10	-0.08	0.16	0.00	0.01	0.26
Corn ending stocks	0.04	-0.11	-0.27	-0.34	-0.24	0.01	-0.01	-0.70	-0.39	-0.43	-0.23	-0.67	0.42	0.36	-0.32	0.24	0.21	0.18	0.23	-0.15	-0.12	0.12
Ethanol mandate(s) compliance cost	-0.44	-0.07	-0.30	-0.06	0.49	-0.47	0.06	0.31	0.18	0.35	0.13	0.35	-0.67	-0.67	0.28	-0.23	-0.18	-0.25	0.15	0.00	0.02	0.27
Biodiesel mandate compliance cost	-0.61	-0.26	-0.43	-0.31	0.58	-0.60	0.19	0.24	0.46	0.28	0.55	0.34	-0.65	-0.66	0.14	-0.68	-0.59	-0.59	0.20	-0.10	0.05	0.22
Total mandate(s) compliance cost	-0.56	-0.16	-0.39	-0.17	0.59	-0.58	0.12	0.32	0.33	0.36	0.32	0.39	-0.75	-0.75	0.25	-0.45	-0.37	-0.42	0.19	-0.04	0.03	0.28
Consumer food price index	0.39	0.37	0.46	0.45	-0.28	0.45	0.17	0.21	0.16	0.17	0.19	0.18	0.20	0.25	0.22	0.14	0.19	-0.03	0.11	-0.13	-0.11	-0.11
Consumer food expenditures	0.41	0.36	0.46	0.44	-0.30	0.46	0.19	0.18	0.14	0.14	0.18	0.14	0.23	0.28	0.20	0.16	0.21	-0.04	0.11	-0.11	-0.12	-0.10
Beef cattle price	-0.01	0.04	0.08	0.09	0.01	0.02	0.10	0.19	0.20	0.17	0.09	0.21	-0.08	-0.07	0.10	-0.05	-0.04	-0.06	0.09	-0.01	-0.04	0.10
Hog price	-0.04	0.08	0.08	0.11	0.05	0.00	0.10	0.22	0.23	0.18	0.09	0.25	-0.12	-0.10	0.13	-0.05	-0.04	-0.06	0.07	-0.01	-0.05	0.06
Wholesale chicken price	-0.01	0.07	0.17	0.24	0.10	0.03	0.11	0.50	0.51	0.45	0.28	0.57	-0.28	-0.25	0.25	-0.21	-0.17	-0.19	0.17	-0.06	0.06	0.19
All milk price	0.01	0.01	0.07	0.11	0.05	0.01	0.04	0.15	0.10	0.14	0.06	0.15	-0.10	-0.08	0.13	-0.01	0.00	-0.03	0.04	0.03	-0.04	0.10

II.b. Causality: energy prices to agricultural and biofuel indicators

Our question goes beyond the extent to which energy prices are correlated with key measures of agricultural and biofuel production and use. We seek to identify how energy price changes cause changes in agricultural and biofuel markets. The hundreds of simulations from the FAPRI-MU structural models give a basis for estimating these effects. We use regressions to reduce all the complicated interactions among variables to a series of coefficients. These regression coefficients measure how the values of key agricultural and biofuel sector indicators in 2019/20 are determined by current and past petroleum prices, no matter how indirect the link.[27] Doing so, we can identify the immediate and delayed effects of a change in energy prices on agricultural and biofuel market indicators. We also represent these effects in absolute terms (the absolute change in the indicator per absolute change in the energy price) and relative terms (the percent change in the indicator per percent change in energy price).[28]

These data are on an annual basis, leading to some mismatch between calendar and marketing year data. The models were developed initially with a focus exclusively on agricultural commodity markets, and we convert renewable fuel standards to a crop marketing year basis to identify clearly the key links, such as corn and soybean oil demand for biofuel production. However, several markets are represented on a calendar year basis, and links between marketing year and calendar year data sometimes work in such a way that a shock that might normally be concurrent appears to take two periods to be transmitted in full. As a rule, crop market data are on the marketing year for that crop. Transportation fuel markets are largely on a marketing year basis to match crop feedstocks, but calendar year aggregates are also generated to validate model output by comparison to published data. Livestock[29], farm income, and consumer food prices and expenditures data are on a calendar basis. Commodity Credit Corporation (CCC) outlays are on a fiscal year basis.

[27] The following discussion will avoid the complicating factor that our estimates of the delayed impacts of petroleum and natural gas prices on indicator variables depend on circumstances in all subsequent years. The most striking example is, again, the potential that biofuel use mandates sever the links between variables. For example, a typically binding biodiesel mandate in 2012/13 marketing year could affect the coefficients on petroleum price lagged 7 years in the regression for the plant price of biodiesel.

[28] The regression relates absolute levels to absolute levels. The conversion to a ratio of percent changes uses the average baseline values of indicator variables and energy prices.

[29] Marketing year crop prices are compared to calendar year livestock production, for example, 2018/19 marketing year crop prices are compared to 2019 livestock production.

Measuring Causality

The estimation results bear a bit more explanation. Take the case of the retail ethanol price (Table 5, far left). The regression takes this form:

$$(\text{Retail ethanol price}_{2019/20,s}) = + a_0$$
$$+ a_{p0}\,(\text{Petroleum price}_{2019,s}) + a_{p1}(\text{Petroleum price}_{2018,s})\ldots + a_{p9}\,(\text{Petroleum price}_{2011,s})$$
$$+ a_{n0}\,(\text{Natural gas price}_{2019,s}) + a_{n1}(\text{Natural gas price}_{2018,s})\ldots + a_{n9}\,(\text{Natural gas price}_{2011,s})$$

where the prices are drawn from each of the 500 simulations and the parameters (a_0, a_{p0}, a_{p1}, … a_{p9}, a_{n0}, a_{n1}, … a_{n9}) are estimated over these data. The parameters reflect the full range of simulation results for all the varying market contexts, including some in which the mandates are more binding than average and others in which the mandates are less binding than average. The results reported in the table summarize the estimated effects as follows.

$a_{p0} = 0.0101$	$a_{p0} + a_{p1} = 0.0116$	$a_{p0} + a_{p1} + \ldots + a_{p9} = 0.0106$
$a_{n0} = 0.0003$	$a_{n0} + a_{n1} = 0.0004$	$a_{n0} + a_{n1} + \ldots + a_{n9} = 0.0004$

These parameter estimates lead us to conclude that a $1 change in the petroleum price per barrel in 2019 is associated with an increase in the retail ethanol price of $0.0101 per gallon in 2019/20. A sustained $1 higher petroleum price increase beginning in 2018 would cause a $0.0116 increase in the retail ethanol price in 2019/20. If the petroleum price were $1 higher over a ten-year period ending in 2019, then the total effect on the ethanol retail price would be an increase of $0.0106. These parameters condense any number of links in the model into a single set of parameters, including this illustrative list:

- Higher petroleum prices cause higher gasoline prices, which induces more consumers to opt to switch to fuels with greater ethanol content. Consumers can adopt E10 quickly, but will not buy E85 unless price signals are strong enough or last long enough to encourage them to buy flex-fuel vehicles.
- Blenders take biofuel use mandates into account, possibly limiting their willingness to provide more ethanol to the market even if consumer demand rises. Blenders also take mandate compliance costs into account, and they see these costs fall as the petroleum price rises.
- Biofuel production capacity and delivery infrastructure are built up over time, implying both delays in response and giving the potential for over-reaction to a change in prices.
- Petroleum price increases affect agricultural commodity production costs, potentially reducing supplies of feedstocks to ethanol production, such as corn, that can affect ethanol prices particularly if mandates are not binding.
- Petroleum price increases cause higher diesel prices, which have their own implications for the markets for transportation fuels, biodiesel, and biodiesel feedstocks that can affect corn and ethanol markets.
- Agricultural commodity market effects of higher petroleum prices, such as the implications of higher production costs on the composition and total volume of crop production.

Turning to the results, the causal impacts of petroleum prices on biofuel markets reinforce much of the preceding discussion (Table 5). A higher petroleum price means a higher ethanol price at retail. The slightly smaller absolute increase at wholesale conventional, or corn-starch ethanol, price reflects two extremes: a binding mandate that largely severs the link between retail and wholesale prices, and a non-binding mandate that allows changes in retail and wholesale prices to be communicated to one another. The full effect of a petroleum price change on these two prices takes place quickly, but that reflects in part the 2019/20 marketing year basis of these numbers, which is after hurdles to E85 expansion are assumed to have been cleared. A 1% increase in the price of petroleum leads to a 0.4% to 0.5% increase in retail ethanol price.

The effect is larger on biodiesel retail price in 2019/20. However, the implications of changes in petroleum prices for biodiesel plant prices is not as large.[30] This reflects the role of the mandate for advanced biofuel use, which rises over the period and is binding in most of our simulations in 2019/20. In the presence of a binding mandate, changes in petroleum prices do not affect the total quantity used, although there can be some effect on the composition of biofuels used to meet the mandate. For example, different impacts on gasoline and diesel markets would lead to different incentives to using sugar-cane ethanol and biodiesel, and potentially to some shifting from one eligible advanced biofuel to another within the still-binding mandate. The net effect on plant price of biodiesel is probably dominated in most of the stochastic simulations by supply effects, such as cross commodity pressures as soybean supplies decline (as shown below).

The rack price of cellulosic ethanol decreases as the petroleum price rises because of our assumptions that the corresponding mandate is waived and that the per-unit cost of this mandate equals the upper limit set by a credit. A higher petroleum price reduces the credit required by the EISA in the event that the cellulosic mandate is waived, as we assume, so an increase in the petroleum price lowers the cellulosic biofuel price. This effect is entirely contemporaneous; lagged effects are small.

One dollar more in the price of petroleum means many millions of dollars less in mandate compliance costs. Higher petroleum prices make it easier to meet the minimum use mandates. Even if a mandate is binding, blenders will not have to discount the biofuel-blended fuel prices as much to sell them to consumers if a high petroleum price lifts demand for these substitutes.

[30] Here, the biodiesel retail price is on a marketing year but the plant price is on a calendar year, which explains the odd pattern in initial and one-year effects.

Table 5. Petroleum and natural gas price effects on biofuel market indicators.

Absolute effects of changes in petroleum and natural gas prices on indicator variables

	Ethanol prices (dollars per gallon)			Biodiesel prices (dollars per gallon)		Mandate compliance costs (millions of dollars)		
	Retail	Rack, conv.	Rack, cell.	Retail	Plant	Ethanol	Biodiesel	Total
Absolute effect of petrolem price								
same year	0.0101	0.0096	-0.0016	0.0159	0.0027	-47.8	-1.8	-49.6
after 1 year	0.0116	0.0102	-0.0003	0.0166	0.0115	-72.9	-5.6	-78.5
after 10 years	0.0106	0.0076	-0.0005	0.0164	0.0109	-111.6	-4.7	-116.3
Absolute effect of natural gas price index								
same year	0.0003	0.0003	-0.0003	0.0007	-0.0001	-2.0	-0.5	-2.6
after 1 year	0.0004	0.0005	-0.0001	0.0006	0.0001	-2.6	-0.7	-3.3
after 10 years	0.0004	0.0006	0.0001	0.0003	-0.0004	6.9	-0.6	6.4

Percent changes in indicator variables relative to percent changes in petroleum and natural gas prices

	Ethanol prices			Biodiesel prices		Mandate compliance costs		
	Retail	Rack, conv.	Rack, cell.	Retail	Plant	Ethanol	Biodiesel	Total
Relative effect of a percent change in petroleum price								
same year	0.40	0.43	-0.04	0.52	0.05	-1.55	-0.15	-1.16
after 1 year	0.46	0.46	-0.01	0.54	0.22	-2.36	-0.46	-1.83
after 10 years	0.42	0.34	-0.01	0.53	0.21	-3.62	-0.39	-2.71
Relative effect of a percent change in natural gas price index								
same year	0.03	0.04	-0.02	0.06	-0.01	-0.18	-0.12	-0.17
after 1 year	0.05	0.06	-0.01	0.05	0.01	-0.23	-0.17	-0.22
after 10 years	0.04	0.08	0.01	0.03	-0.02	0.63	-0.13	0.41

The natural gas price has indirect impacts on biofuel markets such as increasing costs to crop production and biofuel processing. Both forces tend to decrease ethanol supplies and push these prices higher. The natural gas price has mixed effects on biodiesel markets because it also encourages a reallocation of land away from corn to soybeans primarily through changes in fertilizer costs (see below). In all cases, the natural gas price impacts on biofuel markets are much more modest than the effects of the petroleum price.

Table 6. Petroleum and natural gas price effects on crop market indicators.

Absolute effects of changes in petroleum and natural gas prices on indicator variables

	Crop and crop product prices					Crop area results		
	Corn ($/bu)	Sb. Oil ($/cwt)	Sb. Meal ($/ton)	Wheat ($/bu)	Dist. Gr. ($/ton)	Total (millions of acres)	Corn	Soybean
Absolute effect of petrolem price								
same year	0.009	0.122	0.023	0.004	0.138	-0.005	0.001	-0.003
after 1 year	0.006	0.106	0.036	0.007	0.013	0.016	0.071	-0.035
after 10 years	0.009	0.129	0.003	0.007	-0.074	0.032	0.145	-0.066
Absolute effect of natural gas price index								
same year	0.000	0.004	-0.011	0.000	0.003	-0.001	-0.001	-0.001
after 1 year	0.001	0.000	0.011	0.001	0.032	-0.004	-0.004	0.006
after 10 years	-0.001	-0.008	-0.130	0.000	-0.016	-0.005	-0.017	0.012

Percent changes in indicator variables relative to percent changes in petroleum and natural gas prices

	Crop and crop product prices					Crop area results		
	Corn	Sb. Oil	Sb. Meal	Wheat	Dist. Gr.	Total	Corn	Soybean
Relative effect of a percent change in petroleum price								
same year	0.20	0.23	0.01	0.07	0.09	0.00	0.00	0.00
after 1 year	0.13	0.20	0.01	0.11	0.01	0.01	0.07	-0.04
after 10 years	0.21	0.25	0.00	0.12	-0.05	0.01	0.14	-0.07
Relative effect of a percent change in natural gas price index								
same year	0.00	0.02	-0.01	0.00	0.01	0.00	0.00	0.00
after 1 year	0.03	0.00	0.01	0.03	0.06	0.00	-0.01	0.02
after 10 years	-0.04	-0.04	-0.11	0.00	-0.03	-0.01	-0.04	0.04

An increase in the natural gas price causes a reallocation of crop area from corn to soybeans, as well as a reduction in overall crop land use (Table 6). The contemporaneous effects on crop area are insignificant, but grow over time with a 1% change in natural gas price eventually leading to -0.04% change in corn area, +0.04% soybean area, and -0.01% total area. Greater soybean supplies leads to a small reduction in soybean product prices, whereas corn and wheat prices are largely unchanged. These effects are presumably dominated by the role of natural gas in determining costs of crop production, but the effect on biofuel refining costs also plays a small role by affecting crop and crop product demands.

The petroleum price affects crop supplies mostly through its impact on costs. The petroleum price also affect demands for crops and crop products, unless mandates are binding. Both effects tend to raise prices, and the petroleum price is observed to have a large impact on the crop prices. The contemporaneous effect demonstrates the strong demand-side pull on prices even before supply has a chance to respond to the higher costs. In direct contrast to the negative supply-side shock from a increase in natural gas prices, a higher petroleum price draws some land from soybeans into corn and increases total crop area. Like many of the other results discussed here, the case would be quite different if the part of the mandate that applies to conventional ethanol were binding in more of the simulations. When binding, the petroleum price effect on biofuel demand would not substantively affect the volume of corn-starch ethanol produced and consequently changes in petroleum prices would not affect corn and soybean oil demand, but would continue to affect production costs.

Higher petroleum and natural gas prices mean higher food expenditures for consumers (Table 7). A high petroleum price draws more agricultural commodities into a competing demand, as shown before. Moreover, food expenditures rise with the costs of producing, transporting, and processing agricultural commodities and other inputs that depend in part on energy prices. Food expenditure rise by 0.08% initially and 0.14% after ten years for a 1% change in petroleum price, and these changes amount to billions of dollars more money spent on food annually.

Table 7. Petroleum and natural gas price effects on taxpayers, food consumers, and farmers.

Absolute effects of changes in petroleum and natural gas prices on indicator variables

	Government costs	Consumer effects	Farm effects	
	CCC	Expend.	Costs	Net Inc
		(billions of dollars)		
Absolute effect of petrolem price				
same year	0.000	1.538	0.132	-0.063
after 1 year	-0.001	2.187	0.153	0.080
after 10 years	-0.004	2.545	0.292	0.108
Absolute effect of natural gas price index				
same year	0.000	0.100	0.048	-0.043
after 1 year	0.000	0.541	0.068	-0.042
after 10 years	0.000	0.479	0.019	-0.048

Percent changes in indicator variables relative to percent changes in petroleum and natural gas prices

	Government costs	Consumer effects	Farm effects	
	CCC	Expend.	Costs	Net Inc
Relative effect of a percent change in petroleum price				
same year	0.00	0.08	0.03	-0.06
after 1 year	0.00	0.12	0.04	0.08
after 10 years	0.00	0.14	0.07	0.11
Relative effect of a percent change in natural gas price index				
same year	0.00	0.01	0.03	-0.12
after 1 year	0.00	0.08	0.05	-0.12
after 10 years	0.00	0.07	0.01	-0.14

The natural gas price affects costs, and an increase in the natural gas price that increases costs of producing or using agricultural commodities will tend to decrease farm income. The effects are not inconsequential, with a 1% increase in natural gas price causing an initial -0.12% change in net farm income initially. In contrast, the petroleum price affects crop prices through its impact on biofuel prices, particularly in 2019/20 when the relevant mandate is typically not binding, as well as through production and processing costs. Higher input and output prices have opposite effects on income associated with crop production. Livestock producers pay more for energy-related inputs and for feed as petroleum prices rise, so their net farm income likely falls.

The implications of changes in petroleum and natural gas prices for budgetary expenditures on traditional commodity programs, the CCC outlays, are to reduce them. To the extent that price-triggered programs such as counter-cyclical payments make payments, the higher agricultural commodity prices caused by higher energy prices means less payments. The reductions amount to millions of dollars less in taxpayer costs, after ten years, but these constitute very small percent changes in comparison to a CCC budget in the billions of dollars. Not shown are impacts on budgetary expenditures on the crop insurance program. In the short run, higher commodity prices are associated with lower indemnities paid to producers purchasing revenue insurance products. In the long run, however, higher prices increase the value of crops insured, which means higher premiums and an increase in premium subsidies. Thus, in the long run, higher crop prices result in reduced CCC expenditures on traditional farm programs, but an increase in crop insurance outlays.

II.c. Omissions and limitations of our approach

Our measures of correlation and causality rest on the FAPRI-MU stochastic model. There are parts of that model that we continue to improve, such as the representation of costs of production that is described in section IV. The more general point is that our measures of energy price effects on agricultural and biofuel markets depend on the accuracy of our models. These models represent real world decisions by all producers, traders, and users of these commodities in part by simplifying the problem to a manageable amount of data with a limited number of equations – albeit numbering in the thousands – and approximate how all these agents will behave in aggregate.

Stochastic simulations conducted at FAPRI-MU do not capture the full range of possible market variability. As noted before, we look at annual data, so we do not consider intra-year volatility. In addition, the process draws randomly on only a certain set of determining factors, albeit a set that we view to be critically important, not all factors. Technically, the goal of stochastic simulations is not to estimate market volatility, but instead to enable analysts to study the role of agricultural and biofuel policies in a variety of possible market contexts.

The previous set of results is contingent on a general state in which mandates do or do not tend to be binding. In the next section, we adjust the context to increase or decrease the share of simulation results with a binding mandate and measure again the underlying relationships.

III. Energy-to-agriculture links in different contexts

The biofuel mandates can affect the links between energy and agricultural sectors. We explore this effect further in this section. We use the same techniques as in the previous section that traces energy price impacts on key indicators of the agricultural sector, but we apply them to alternative cases. To make an alternative case, we change selected assumptions. Then, we re-run all the 500 stochastic simulations with this new assumption in place. Based on the stochastic model output, we re-examine our correlation statistics and regression coefficients that represent the links between energy prices and key indicators of agricultural and biofuel markets.

III.a. No biofuel tax credits, tariff, or mandates

A alternative scenario which highlights the effects of biofuel policies is between the base case, with mandates expanding according to the underlying law and biofuel tax credits and ethanol tariff are extended, to an alternative case where credits and tariffs are allowed to expire and mandates are eliminated. In the base case, we extend indefinitely the $1.00 per gallon biodiesel blenders tax credit, the ethanol blenders credit of $0.45 per gallon and specific tariff of $0.54 per gallon, and the cellulosic producers credit of $1.01per gallon. In the alternative case, all these credits and tariff are eliminated from 2010/11 marketing year on. Legislation does not determine that the biofuel use mandates will expire in the ten-year projection period, but are arbitrarily eliminated for the 2010/11 crop year on for the purposes of this experiment. The elimination of the biofuel use mandate should in principle strengthen the relationship between petroleum and agricultural markets because the elimination of mandates strengthens the ties between the biofuel feedstock supply and biofuel consumer demand.

Correlation among key indicators in 2011/12 give evidence that the links are stronger without the biofuel policies in place (Table 8). With the elimination of biofuel policies, there is a single ethanol price, not distinct prices according to the mandate the biofuel helps to meet. As a consequence, the correlation of all ethanol prices and the petroleum price are the same, 0.77. In the base case with biofuel policies, the petroleum price was more correlated with the retail price and less correlated with the conventional rack price, reflecting the instances when quantity was bound by the mandate (so the full effect of demand changes fell on the retail price without being passed on into the wholesale market). The correlation between petroleum price and the cellulosic ethanol price has reversed, going from negative in the base case – when the effect was driven by the credit that must be offered in the event that the cellulosic mandate is waived – to positive when there is no policy barrier to separate the price of cellulosic ethanol from any other ethanol price.

Petroleum price changes are likely to have greater effects on feedstock markets in the absence of biofuel policies. The 2011/12 statistics show stronger correlation between petroleum price and quantities in the corn market, culminating in an increase in the correlation between petroleum and corn prices that is 0.25 in the absence of biofuel policy as compared to 0.09 in the base case.

The interaction between biodiesel, biodiesel feedstock markets, and petroleum is also affected in a similar way. In the base case, the rising biodiesel mandate is frequently binding in 2011/12, so petroleum price impacts on biodiesel demand were usually not communicated on to the wholesale biodiesel market, let alone to soybean oil and other crop markets. Removing biofuel policies results in the correlation between petroleum and rack biodiesel price rising from 0.22 in the base case to 0.64 in the scenario. The petroleum price is more correlated with biodiesel use (from 0.56 in the base case to 0.84 in the no biofuel policy case) and the soybean oil price (0.26 to 0.47). The petroleum price is more correlated with other crop market indicators in 2011/12 if biofuel policies are not in place.

The correlation between the natural gas price and agricultural and biofuel market indicators are changed only slightly by the removal of biofuel policies. The greater correlation with biofuel market quantities, such as ethanol use (rising from 0.16 in the base case to 0.20) and biodiesel use (0.23 to 0.37) suggest that there is greater responsiveness of these markets to changes in crop and biofuel production costs in the absence of biofuel policies.

Table 8. Correlations among variables in 2011/12 with no biofuel policies.

	Oil price$_t$	Natural gas	Ethanol price (retail eqv.)	Ethanol price (rack)	Cellulosic ethanol price (rack)	Biodiesel price (retail eqv.)	Biodiesel price (rack)	Corn farm price	Soybean farm price	Wheat price	Soybean oil price	Distillers grains price (DDGS)	Ethanol production	Ethanol use	Ethanol net-imports	Biodiesel production	Biodiesel use	Biodiesel net exports	Corn area planted	Soybean area planted	Wheat area planted	Total crop area planted*
Oil price$_t$	1.00	0.26	0.77	0.77	0.77	0.95	0.64	0.25	0.17	0.10	0.47	0.04	0.76	0.79	-0.28	0.74	0.84	-0.79	0.08	-0.09	-0.04	-0.05
Natural gas	0.26	1.00	0.41	0.41	0.41	0.34	0.29	0.12	0.04	0.07	0.14	0.06	0.11	0.20	0.19	0.32	0.37	-0.37	-0.07	0.03	-0.13	-0.19
Ethanol price (retail eqv.)	0.77	0.41	1.00	1.00	1.00	0.81	0.60	0.75	0.42	0.44	0.57	0.55	0.35	0.54	0.35	0.52	0.65	-0.77	-0.04	0.01	-0.02	-0.12
Ethanol price (rack)	0.77	0.41	1.00	1.00	1.00	0.81	0.60	0.75	0.42	0.44	0.57	0.55	0.35	0.54	0.35	0.52	0.65	-0.77	-0.04	0.01	-0.02	-0.12
Cellulosic ethanol price (rack)	0.77	0.41	1.00	1.00	1.00	0.81	0.60	0.75	0.42	0.44	0.57	0.55	0.35	0.54	0.35	0.52	0.65	-0.77	-0.04	0.01	-0.02	-0.12
Biodiesel price (retail eqv.)	0.95	0.34	0.81	0.81	0.81	1.00	0.67	0.30	0.26	0.14	0.56	0.10	0.76	0.82	-0.18	0.66	0.80	-0.90	0.12	-0.12	-0.07	-0.06
Biodiesel price (rack)	0.64	0.29	0.60	0.60	0.60	0.67	1.00	0.21	0.22	0.11	0.43	0.07	0.62	0.73	-0.02	0.47	0.61	-0.76	0.30	-0.23	-0.23	0.01
Corn farm price	0.25	0.12	0.75	0.75	0.75	0.30	0.21	1.00	0.64	0.67	0.49	0.93	-0.28	-0.05	0.72	-0.03	0.07	-0.32	-0.10	0.05	0.09	-0.06
Soybean farm price	0.17	0.04	0.42	0.42	0.42	0.26	0.22	0.64	1.00	0.44	0.73	0.79	-0.10	0.04	0.39	-0.27	-0.12	-0.34	0.30	-0.39	0.16	0.02
Wheat price	0.10	0.07	0.44	0.44	0.44	0.14	0.11	0.67	0.44	1.00	0.37	0.66	-0.28	-0.14	0.50	-0.12	-0.05	-0.18	0.27	-0.13	0.00	0.23
Soybean oil price	0.47	0.14	0.57	0.57	0.57	0.56	0.43	0.49	0.73	0.37	1.00	0.47	0.21	0.32	0.21	-0.04	0.15	-0.63	0.27	-0.23	0.01	0.08
Distillers grains price (DDGS)	0.04	0.06	0.55	0.55	0.55	0.10	0.07	0.93	0.79	0.66	0.47	1.00	-0.43	-0.22	0.73	-0.24	-0.15	-0.15	0.00	-0.07	0.15	-0.04
Ethanol production	0.76	0.11	0.35	0.35	0.35	0.76	0.62	-0.28	-0.10	-0.28	0.21	-0.43	1.00	0.95	-0.58	0.68	0.76	-0.70	0.17	-0.18	-0.09	-0.06
Corn-starch ethanol production	0.76	0.10	0.34	0.34	0.34	0.76	0.61	-0.28	-0.10	-0.27	0.21	-0.43	1.00	0.95	-0.58	0.67	0.76	-0.70	0.17	-0.19	-0.09	-0.06
Cellulosic ethanol production	0.51	0.38	0.78	0.78	0.78	0.55	0.46	0.61	0.33	0.28	0.39	0.46	0.24	0.42	0.35	0.35	0.46	-0.59	-0.18	0.05	0.07	-0.22
Ethanol use	0.79	0.20	0.54	0.54	0.54	0.82	0.73	-0.05	0.04	-0.14	0.32	-0.22	0.95	1.00	-0.30	0.69	0.80	-0.82	0.13	-0.17	-0.09	-0.12
E85 Ethanol use	0.69	0.22	0.48	0.48	0.48	0.64	0.60	0.01	0.03	-0.07	0.31	-0.12	0.54	0.55	-0.22	0.63	0.67	-0.50	0.05	-0.09	-0.08	-0.11
Ethanol net-imports	-0.28	0.19	0.35	0.35	0.35	-0.18	-0.02	0.72	0.39	0.50	0.21	0.73	-0.58	-0.30	1.00	-0.27	-0.23	0.01	-0.14	0.10	0.03	-0.08
Biodiesel production	0.74	0.32	0.52	0.52	0.52	0.66	0.47	-0.03	-0.27	-0.12	-0.04	-0.24	0.68	0.69	-0.27	1.00	0.97	-0.52	-0.08	0.07	-0.09	-0.14
Biodiesel use	0.84	0.37	0.65	0.65	0.65	0.80	0.61	0.07	-0.12	-0.05	0.15	-0.15	0.76	0.80	-0.23	0.97	1.00	-0.72	-0.01	0.01	-0.11	-0.12
Biodiesel net exports	-0.79	-0.37	-0.77	-0.77	-0.77	-0.90	-0.76	-0.32	-0.34	-0.18	-0.63	-0.15	-0.70	-0.82	0.01	-0.52	-0.72	1.00	-0.21	0.17	0.13	0.03
Corn area planted	0.08	-0.07	-0.04	-0.04	-0.04	0.12	0.30	-0.10	0.30	0.27	0.27	0.00	0.17	0.13	-0.14	-0.08	-0.01	-0.21	1.00	-0.71	-0.06	0.58
Soybean area planted	-0.09	0.03	0.01	0.01	0.01	-0.12	-0.23	0.05	-0.39	-0.13	-0.23	-0.07	-0.18	-0.17	0.10	0.07	0.01	0.17	-0.71	1.00	-0.28	0.03
Wheat area planted	-0.04	-0.13	-0.02	-0.02	-0.02	-0.07	-0.23	0.09	0.16	0.00	0.01	0.15	-0.09	-0.09	0.03	-0.09	-0.11	0.13	-0.06	-0.28	1.00	0.00
Total crop area planted*	-0.05	-0.19	-0.12	-0.12	-0.12	-0.06	0.01	-0.06	0.02	0.23	0.08	-0.04	-0.06	-0.12	-0.08	-0.14	-0.12	0.03	0.58	0.03	0.00	1.00
Corn cost of production	0.16	0.36	0.28	0.28	0.28	0.19	0.10	0.21	0.08	0.13	0.12	0.17	-0.03	0.02	0.17	0.12	0.16	-0.19	-0.11	0.03	-0.15	-0.31
Soybeans cost of production	0.26	0.23	0.33	0.33	0.33	0.29	0.17	0.23	0.11	0.11	0.17	0.16	0.08	0.13	0.11	0.19	0.24	-0.27	-0.06	-0.02	-0.10	-0.28
Corn production	0.16	-0.11	-0.25	-0.25	-0.25	0.13	0.15	-0.56	-0.28	-0.11	-0.04	-0.56	0.45	0.30	-0.56	0.16	0.17	-0.12	0.48	-0.24	-0.12	0.37
Corn use for ethanol	0.76	0.10	0.34	0.34	0.34	0.76	0.61	-0.28	-0.10	-0.27	0.21	-0.43	1.00	0.95	-0.58	0.67	0.76	-0.70	0.17	-0.19	-0.09	-0.06
Corn use for feed	-0.44	-0.19	-0.66	-0.66	-0.66	-0.46	-0.31	-0.54	-0.11	-0.10	-0.21	-0.33	-0.17	-0.32	-0.29	-0.38	-0.43	0.42	0.35	-0.27	-0.01	0.21
Corn exports	-0.27	-0.12	-0.13	-0.13	-0.13	-0.27	-0.27	0.11	-0.04	0.43	-0.07	0.14	-0.36	-0.36	0.18	-0.27	-0.29	0.24	0.09	0.06	0.06	0.25
Corn ending stocks	-0.08	-0.12	-0.48	-0.48	-0.48	-0.12	-0.11	-0.69	-0.43	-0.43	-0.27	-0.65	0.24	0.08	-0.52	0.09	0.03	0.17	0.16	-0.11	-0.10	0.08
Ethanol mandate(s) compliance cost	-0.53	-0.17	-0.40	-0.40	-0.40	-0.52	-0.39	-0.06	-0.03	0.07	-0.12	0.04	-0.52	-0.55	0.15	-0.52	-0.57	0.50	-0.02	0.12	-0.02	0.16
Biodiesel mandate compliance cost	0.02	0.04	-0.02	-0.02	-0.02	0.01	0.02	-0.07	-0.09	-0.09	-0.08	-0.09	0.04	0.02	-0.07	0.05	0.04	-0.01	0.03	-0.05	0.03	0.01
Total mandate(s) compliance cost	-0.53	-0.16	-0.40	-0.40	-0.40	-0.52	-0.39	-0.07	-0.04	0.06	-0.12	0.03	-0.51	-0.55	0.14	-0.52	-0.57	0.50	-0.02	0.12	-0.02	0.16
Consumer food price index	0.40	0.37	0.48	0.48	0.48	0.45	0.47	0.27	0.19	0.20	0.28	0.18	0.24	0.34	0.14	0.31	0.40	-0.49	0.16	-0.15	-0.14	-0.09
Consumer food expenditures	0.41	0.36	0.48	0.48	0.48	0.46	0.48	0.24	0.17	0.16	0.28	0.15	0.27	0.36	0.11	0.32	0.41	-0.51	0.16	-0.13	-0.15	-0.08
Beef cattle price	0.01	0.04	0.12	0.12	0.12	0.04	0.07	0.18	0.20	0.17	0.10	0.21	-0.04	0.01	0.17	-0.02	0.01	-0.08	0.09	-0.01	-0.04	0.10
Hog price	-0.01	0.09	0.13	0.13	0.13	0.03	0.07	0.20	0.23	0.16	0.10	0.25	-0.07	0.00	0.22	-0.03	0.00	-0.08	0.07	-0.01	-0.05	0.06
Wholesale chicken price	0.02	0.07	0.28	0.28	0.28	0.06	0.07	0.47	0.50	0.42	0.26	0.56	-0.20	-0.09	0.38	-0.13	-0.07	-0.12	0.17	-0.05	0.05	0.19
All milk price	0.02	0.01	0.09	0.09	0.09	0.02	0.00	0.14	0.10	0.13	0.06	0.14	-0.08	-0.05	0.12	0.00	0.00	0.00	0.03	0.03	-0.04	0.10

In the absence of policy intervention, the effects of an increase in petroleum price are the same on all ethanol prices shown here, in absolute terms (Table 9). Biofuel policies alters the ethanol wholesale market and leads to multiple prices. Without these policies, the impact of a change in petroleum prices is the same for ethanol price at all stages, and for all types, assuming a mostly constant margin between retail and wholesale prices.[31] The cumulative effect of petroleum price on the retail price is lower in the long run when there is no biofuel policy relative to the base case because quantities will change, too. More of the effects of a change in the petroleum price on demand are passed on to biofuel suppliers if the mandate is not binding.

Table 9. Petroleum and natural gas price effects on biofuel market indicators (No policy).

Absolute effects of changes in petroleum and natural gas prices on indicator variables

	Ethanol prices (dollars per gallon)			Biodiesel prices (dollars per gallon)		Mandate compliance costs (millions of dollars)		
	Retail	Rack, conv.	Rack, cell.	Retail	Plant	Ethanol	Biodiesel	Total
Absolute effect of petrolem price								
same year	0.0084	0.0084	0.0084	0.0177	0.0042	0.0	0.0	0.0
after 1 year	0.0080	0.0080	0.0080	0.0177	0.0166	0.0	0.0	0.0
after 10 years	0.0065	0.0065	0.0065	0.0169	0.0151	0.0	0.0	0.0
Absolute effect of natural gas price index								
same year	0.0003	0.0003	0.0003	0.0007	0.0000	0.0	0.0	0.0
after 1 year	0.0006	0.0006	0.0006	0.0005	0.0005	0.0	0.0	0.0
after 10 years	0.0006	0.0006	0.0006	0.0002	-0.0001	0.0	0.0	0.0

Percent changes in indicator variables relative to percent changes in petroleum and natural gas prices

	Ethanol prices			Biodiesel prices		Mandate compliance costs		
	Retail	Rack, conv.	Rack, cell.	Retail	Plant	Ethanol	Biodiesel	Total
Relative effect of a percent change in petroleum price								
same year	0.34	0.38	0.22	0.58	0.08	0.00	0.00	0.00
after 1 year	0.32	0.36	0.21	0.58	0.32	0.00	0.00	0.00
after 10 years	0.26	0.29	0.17	0.55	0.29	0.00	0.00	0.00
Relative effect of a percent change in natural gas price index								
same year	0.03	0.03	0.02	0.06	0.00	0.00	0.00	0.00
after 1 year	0.07	0.07	0.04	0.05	0.03	0.00	0.00	0.00
after 10 years	0.07	0.07	0.04	0.02	0.00	0.00	0.00	0.00

[31] The difference in relative effects is partly due to our application of base case prices in these calculations. In addition, the fixed margin between retail and wholesale prices implies that the retail price is higher than wholesale prices, so the same constant change would imply a smaller percent change in retail price.

An increase in the natural gas price will increase agricultural commodity production costs and biofuel refinery costs. The effects on ethanol prices are a small and uniform increase, and the effect increases once crop producers and biofuel refinery respond to changes in costs of operation.

The impacts of a change in petroleum price on retail and wholesale biodiesel prices are about the same in absolute terms.[32] The total change in plant price was two-thirds as much as the change in retail price in the base case because of the binding advanced mandate (Table 5). In the present case of no policy there is no wedge driven between these two prices, so the effects are very similar in absolute terms. The natural gas price effects on biodiesel are smaller than the impacts on ethanol due in part to the impact on crop mix (discussed below). Mandate compliance costs are zero if there are no mandates.

The same patterns in cumulative crop area impacts emerge as in the base case: a higher petroleum price increases biofuel demand for corn and soybean oil enough to offset the cost effects, leading to more total area and a shift of some area from soybeans into corn (Table 10). As in the base case, higher crop production and biofuel processing costs associated with a higher natural gas price have the opposite effect of lower total area, less corn area, and more soybean area. In the base case, the advanced mandate is the most commonly binding mandate in 2019/20 in these simulations and it can be met with biodiesel made from soybean oil. After eliminating the mandate and other policies, the biggest changes in the estimated links from petroleum price to agricultural commodity prices are seen in soybean product prices. With a frequently binding mandate, the higher petroleum price did not always feed through to greater soybean oil demand by biodiesel refiners. In the no-policy scenario, these markets are linked together, so an increase in the petroleum price is more certain to drive the soybean oil price higher. A higher soybean oil price causes more soybean production and soybean crush, so the additional production of soybean meal co-produced with oil leads as well to a lower co-product soybean meal price.

[32] The initial year effects are different because the retail price is on a marketing year basis and the plant price shown here is on a calendar year basis.

Table 10. Petroleum and natural gas price effects on crop market indicators (No policy).

Absolute effects of changes in petroleum and natural gas prices on indicator variables

	Crop and crop product prices					Crop area results		
	Corn ($/bu)	Sb. Oil ($/cwt)	Sb. Meal ($/ton)	Wheat ($/bu)	Dist. Gr. ($/ton)	Total (millions of acres)	Corn	Soybean
Absolute effect of petrolem price								
same year	0.009	0.125	-0.020	0.004	0.131	-0.007	-0.004	0.000
after 1 year	0.005	0.136	-0.025	0.006	0.021	0.018	0.074	-0.036
after 10 years	0.007	0.155	-0.189	0.005	-0.026	0.028	0.114	-0.045
Absolute effect of natural gas price index								
same year	0.000	0.006	-0.019	0.000	0.000	-0.003	-0.001	-0.001
after 1 year	0.001	0.004	0.000	0.001	0.029	-0.004	-0.005	0.007
after 10 years	-0.001	-0.007	-0.118	0.000	-0.023	-0.005	-0.015	0.010

Percent changes in indicator variables relative to percent changes in petroleum and natural gas prices

	Crop and crop product prices					Crop area results		
	Corn	Sb. Oil	Sb. Meal	Wheat	Dist. Gr.	Total	Corn	Soybean
Relative effect of a percent change in petroleum price								
same year	0.19	0.24	-0.01	0.07	0.09	0.00	0.00	0.00
after 1 year	0.11	0.26	-0.01	0.11	0.01	0.01	0.07	-0.04
after 10 years	0.17	0.30	-0.06	0.09	-0.02	0.01	0.11	-0.05
Relative effect of a percent change in natural gas price index								
same year	-0.01	0.03	-0.02	-0.01	0.00	0.00	0.00	0.00
after 1 year	0.04	0.02	0.00	0.03	0.05	0.00	-0.01	0.02
after 10 years	-0.05	-0.04	-0.10	-0.01	-0.04	0.00	-0.04	0.03

The effects of energy prices on CCC expenditures, consumer food expenditures, and farm income are almost the similar with or without the mandate (Table 11). In the case of farm income, the cumulative effect of changes in the petroleum price is approximately halved in the long run. The cumulative impacts of natural gas price changes on these indicators are almost unchanged.

Table 11. Petroleum and natural gas price effects on taxpayers, food consumers, and farmers (No policy).

Absolute effects of changes in petroleum and natural gas prices on indicator variables

	Government costs	Consumer effects	Farm effects	
	CCC	Expend.	Costs	Net Inc
		(billions of dollars)		
Absolute effect of petrolem price				
same year	0.000	1.534	0.129	-0.068
after 1 year	-0.001	2.196	0.154	0.070
after 10 years	-0.001	2.527	0.267	0.059
Absolute effect of natural gas price index				
same year	0.000	0.099	0.047	-0.043
after 1 year	-0.001	0.541	0.067	-0.040
after 10 years	-0.001	0.473	0.018	-0.046

Percent changes in indicator variables relative to percent changes in petroleum and natural gas prices

	Government costs	Consumer effects	Farm effects	
	CCC	Expend.	Costs	Net Inc
Relative effect of a percent change in petroleum price				
same year	0.00	0.08	0.03	-0.07
after 1 year	0.00	0.12	0.04	0.07
after 10 years	0.00	0.13	0.07	0.06
Relative effect of a percent change in natural gas price index				
same year	0.00	0.01	0.03	-0.12
after 1 year	0.00	0.08	0.05	-0.12
after 10 years	0.00	0.07	0.01	-0.13

III.b. Greater demand for US corn exports.

We can more fully explore a binding mandate through a more direct effect on corn markets. One outcome which is likely to make the overall mandate binding is greater demand for corn exports from our international trading partners.

In this scenario, the demand curve for corn exports from the U.S. is shifted out by 500 million bushels in all years of the simulation. This shift in the export demand curve does not cause an equal increase in the quantity of exports; the net change in corn exports will be less than 500 million bushels as the price will be bid higher as the market adjusts to greater demand for exports. The scenario is a stylized one where only demand for corn is affected. Other domestic demands for corn are left unchanged. We also leave domestic demand behavior and trade of all other commodities unchanged. Again, however, the quantities will change even if we assume no shift owing to a new set of fundamental factors: the higher corn export demand leads to a higher corn price that affects supplies of other crops, feed uses and livestock product markets, and biofuel markets.

The size of the shock is not inconsequential. A 500 million bushel increase, if realized, would represent 20% to 25% of corn exports, on average. While large, it represents a plausible export demand path and a suitable scenario to explore the effects of a more frequently binding mandate. Results in the short run are more pronounced because of three reasons. First, the shock is constant (as opposed to starting small and building over time). Second, the potential for corn starch ethanol to help the meet the mandate rises until 2015, and it is more likely to be binding in those early years. Third, corn starch ethanol is the dominant biofuel in the near-term future simulations whereas other biofuels might be able to offset corn starch ethanol shocks in later years.

The increase in corn demand drives corn price higher, so the mandate is more likely to be binding. Correlation between the oil price and retail ethanol price is similar to the base case in 2011/12 crop year, while the correlation between the petroleum price and wholesale ethanol prices are reduced (Table 12). Because the mandate is more binding and therefore more often the factor that determines the quantity of ethanol produced, the correlation between ethanol production and the ethanol rack price falls from 0.22 in the base case to 0.10 when export demand is shifted out. In the 2011/12 crop year, the correlation between petroleum and corn prices remains quite low, at 0.09. In the short run, yield fluctuations are more important than petroleum prices to the determination of corn prices as long as mandates tend to be binding. Impacts on biodiesel and biodiesel feedstock market correlations are the consequence of connections to the corn market, namely cross-effects in area reallocation and use, but these impacts amount to small changes from the base case.

Table 12. Correlations among variables in 2011/12 with increased corn export demand.

	Oil price$_t$	Natural gas	Ethanol price (retail eqv.)	Ethanol price (rack)	Cellulosic ethanol price (rack)	Biodiesel price (retail eqv.)	Biodiesel price (rack)	Corn farm price	Soybean farm price	Wheat price	Soybean oil price	Distillers grains price (DDGS)	Ethanol production	Ethanol use	Ethanol net-imports	Biodiesel production	Biodiesel use	Biodiesel net exports	Corn area planted	Soybean area planted	Wheat area planted	Total crop area planted*
Oil price$_t$	1.00	0.26	0.81	0.69	-0.72	0.96	0.20	0.09	0.12	0.03	0.24	0.01	0.69	0.77	-0.01	0.46	0.53	0.12	0.02	-0.05	0.00	-0.08
Natural gas	0.26	1.00	0.39	0.39	-0.22	0.35	0.03	0.10	0.02	0.06	0.05	0.07	0.09	0.15	0.16	0.20	0.22	0.07	-0.08	0.04	-0.12	-0.20
Ethanol price (retail eqv.)	0.81	0.39	1.00	0.93	-0.39	0.85	0.18	0.51	0.29	0.27	0.34	0.41	0.33	0.48	0.33	0.30	0.37	0.01	-0.16	0.05	0.02	-0.22
Ethanol price (rack)	0.69	0.39	0.93	1.00	-0.23	0.72	0.22	0.67	0.38	0.44	0.42	0.58	0.10	0.26	0.50	0.24	0.33	-0.08	-0.11	0.06	0.03	-0.13
Cellulosic ethanol price (rack)	-0.72	-0.22	-0.39	-0.23	1.00	-0.77	-0.16	0.27	0.04	0.14	-0.10	0.29	-0.77	-0.78	0.25	-0.36	-0.38	-0.16	-0.19	0.11	0.09	-0.05
Biodiesel price (retail eqv.)	0.96	0.35	0.85	0.72	-0.77	1.00	0.20	0.12	0.17	0.06	0.30	0.05	0.68	0.78	0.03	0.38	0.45	0.05	0.04	-0.08	-0.03	-0.12
Biodiesel price (rack)	0.20	0.03	0.18	0.22	-0.16	0.20	1.00	0.06	0.11	0.26	0.39	0.03	0.13	0.15	0.10	0.08	0.21	-0.26	0.30	0.16	-0.31	0.51
Corn farm price	0.09	0.10	0.51	0.67	0.27	0.12	0.06	1.00	0.59	0.68	0.43	0.96	-0.56	-0.43	0.63	-0.26	-0.22	-0.25	-0.15	0.08	0.11	-0.07
Soybean farm price	0.12	0.02	0.29	0.38	0.04	0.17	0.11	0.59	1.00	0.46	0.78	0.74	-0.24	-0.17	0.37	-0.53	-0.44	-0.50	0.31	-0.44	0.19	-0.02
Wheat price	0.03	0.06	0.27	0.44	0.14	0.06	0.26	0.68	0.46	1.00	0.39	0.68	-0.40	-0.33	0.44	-0.21	-0.15	-0.24	0.27	-0.15	0.00	0.21
Soybean oil price	0.24	0.05	0.34	0.42	-0.10	0.30	0.39	0.43	0.78	0.39	1.00	0.49	-0.05	0.03	0.32	-0.48	-0.32	-0.63	0.28	-0.28	0.06	0.06
Distillers grains price (DDGS)	0.01	0.07	0.41	0.58	0.29	0.05	0.03	0.96	0.74	0.68	0.49	1.00	-0.60	-0.48	0.64	-0.36	-0.32	-0.31	-0.04	-0.05	0.15	-0.06
Ethanol production	0.69	0.09	0.33	0.10	-0.77	0.68	0.13	-0.56	-0.24	-0.40	-0.05	-0.60	1.00	0.97	-0.53	0.45	0.47	0.22	0.11	-0.11	-0.08	-0.04
Corn-starch ethanol production	0.68	0.08	0.31	0.08	-0.77	0.68	0.13	-0.56	-0.24	-0.39	-0.05	-0.60	1.00	0.97	-0.54	0.44	0.46	0.21	0.12	-0.12	-0.07	-0.03
Cellulosic ethanol production	-0.67	-0.21	-0.53	-0.48	0.76	-0.72	-0.42	-0.14	-0.29	-0.27	-0.38	-0.13	-0.43	-0.50	-0.08	-0.17	-0.24	0.06	-0.36	0.15	0.10	-0.28
Ethanol use	0.77	0.15	0.48	0.26	-0.78	0.78	0.15	-0.43	-0.17	-0.33	0.03	-0.48	0.97	1.00	-0.31	0.48	0.50	0.21	0.07	-0.10	-0.07	-0.09
E85 Ethanol use	0.81	0.24	0.66	0.57	-0.53	0.80	0.22	-0.11	-0.01	-0.13	0.14	-0.17	0.68	0.78	0.02	0.48	0.54	0.14	0.02	-0.08	-0.05	-0.13
Ethanol net-imports	-0.01	0.16	0.33	0.50	0.25	0.03	0.10	0.63	0.37	0.44	0.32	0.64	-0.53	-0.31	1.00	-0.09	-0.05	-0.14	-0.07	0.05	0.02	-0.04
Biodiesel production	0.46	0.20	0.30	0.24	-0.36	0.38	0.08	-0.26	-0.53	-0.21	-0.48	-0.36	0.45	0.48	-0.09	1.00	0.95	0.69	-0.20	0.31	-0.13	0.01
Biodiesel use	0.53	0.22	0.37	0.33	-0.38	0.45	0.21	-0.22	-0.44	-0.15	-0.32	-0.32	0.47	0.50	-0.05	0.95	1.00	0.42	-0.14	0.30	-0.14	0.08
Biodiesel net exports	0.12	0.07	0.01	-0.08	-0.16	0.05	-0.26	-0.25	-0.50	-0.24	-0.63	-0.31	0.22	0.21	-0.14	0.69	0.42	1.00	-0.25	0.20	-0.03	-0.14
Corn area planted	0.02	-0.08	-0.16	-0.11	-0.19	0.04	0.30	-0.15	0.31	0.27	0.28	-0.04	0.11	0.07	-0.07	-0.20	-0.14	-0.25	1.00	-0.73	-0.05	0.54
Soybean area planted	-0.05	0.04	0.05	0.06	0.11	-0.08	0.16	0.08	-0.44	-0.15	-0.28	-0.05	-0.11	-0.10	0.05	0.31	0.30	0.20	-0.73	1.00	-0.28	0.05
Wheat area planted	0.00	-0.12	0.02	0.03	0.09	-0.03	-0.31	0.11	0.19	0.00	0.06	0.15	-0.08	-0.07	0.02	-0.13	-0.14	-0.03	-0.05	-0.28	1.00	-0.01
Total crop area planted*	-0.08	-0.20	-0.22	-0.13	-0.05	-0.12	0.51	-0.07	-0.02	0.21	0.06	-0.06	-0.04	-0.09	-0.04	0.01	0.08	-0.14	0.54	0.05	-0.01	1.00
Corn cost of production	0.16	0.36	0.23	0.27	-0.11	0.19	0.02	0.19	0.08	0.14	0.10	0.16	-0.02	0.01	0.16	0.05	0.06	0.00	-0.07	0.00	-0.15	-0.30
Soybeans cost of production	0.26	0.23	0.30	0.31	-0.20	0.29	0.04	0.18	0.10	0.10	0.13	0.15	0.07	0.11	0.14	0.08	0.11	0.00	-0.03	-0.04	-0.10	-0.28
Corn production	0.12	-0.12	-0.24	-0.33	-0.36	0.09	0.18	-0.63	-0.27	-0.13	-0.09	-0.60	0.50	0.42	-0.41	0.15	0.17	0.03	0.48	-0.26	-0.11	0.36
Corn use for ethanol	0.68	0.08	0.32	0.08	-0.77	0.68	0.13	-0.56	-0.24	-0.39	-0.05	-0.60	1.00	0.97	-0.54	0.44	0.46	0.21	0.12	-0.12	-0.07	-0.03
Corn use for feed	-0.16	-0.16	-0.46	-0.53	-0.12	-0.18	0.02	-0.62	-0.08	-0.17	-0.06	-0.49	0.26	0.17	-0.36	-0.07	-0.07	-0.05	0.47	-0.39	-0.05	0.20
Corn exports	-0.17	-0.12	-0.18	-0.13	0.10	-0.19	0.09	0.03	-0.08	0.37	-0.02	0.02	-0.16	-0.19	0.00	-0.09	-0.08	-0.07	0.15	0.01	0.01	0.26
Corn ending stocks	0.06	-0.10	-0.26	-0.36	-0.26	0.03	0.01	-0.67	-0.36	-0.41	-0.21	-0.64	0.45	0.39	-0.31	0.23	0.22	0.16	0.23	-0.15	-0.12	0.11
Ethanol mandate(s) compliance cost	-0.50	-0.10	-0.40	-0.05	0.50	-0.53	0.07	0.29	0.16	0.36	0.13	0.33	-0.64	-0.65	0.36	-0.23	-0.18	-0.26	0.17	0.00	0.02	0.30
Biodiesel mandate compliance cost	-0.60	-0.26	-0.44	-0.25	0.56	-0.60	0.22	0.24	0.47	0.29	0.58	0.34	-0.61	-0.64	0.24	-0.66	-0.58	-0.57	0.20	-0.12	0.05	0.19
Total mandate(s) compliance cost	-0.58	-0.16	-0.46	-0.12	0.57	-0.60	0.13	0.30	0.28	0.37	0.29	0.36	-0.70	-0.71	0.35	-0.40	-0.33	-0.38	0.20	-0.04	0.03	0.30
Consumer food price index	0.39	0.37	0.46	0.43	-0.28	0.45	0.16	0.20	0.17	0.18	0.19	0.17	0.17	0.24	0.16	0.12	0.17	-0.03	0.13	-0.14	-0.11	-0.12
Consumer food expenditures	0.41	0.36	0.45	0.42	-0.31	0.46	0.18	0.17	0.15	0.14	0.18	0.14	0.20	0.27	0.14	0.14	0.19	-0.03	0.13	-0.12	-0.12	-0.11
Beef cattle price	0.00	0.04	0.08	0.10	0.01	0.02	0.10	0.17	0.19	0.17	0.09	0.19	-0.08	-0.07	0.10	-0.04	-0.03	-0.05	0.09	-0.03	-0.03	0.09
Hog price	-0.03	0.08	0.08	0.12	0.05	0.00	0.10	0.20	0.22	0.18	0.10	0.24	-0.13	-0.11	0.14	-0.05	-0.04	-0.04	0.08	-0.02	-0.04	0.06
Wholesale chicken price	-0.01	0.07	0.17	0.27	0.09	0.03	0.11	0.47	0.49	0.44	0.27	0.54	-0.28	-0.24	0.28	-0.20	-0.17	-0.17	0.17	-0.09	0.07	0.17
All milk price	0.01	0.00	0.07	0.12	0.05	0.01	0.04	0.15	0.10	0.14	0.06	0.15	-0.11	-0.08	0.14	0.00	0.00	-0.02	0.03	0.04	-0.04	0.10

In the presence of increased export demand and consequently a more binding mandate, the effects of an increase in petroleum price on retail ethanol price and mandates costs is somewhat stronger (Table 13). The link between petroleum and ethanol retail prices through competition in transportation fuels remains, but more instances of a binding mandate means that the link between ethanol retail and rack (wholesale) prices is weakened.

For example, if the mandate is not binding in one of the stochastic simulations of the base case, then a lower petroleum price might cause lower ethanol demand, leading to lower quantities of ethanol use and production, and lower ethanol prices. If the greater corn demand leads to a binding mandate, then this same lower petroleum price and resulting weakness in ethanol demand cannot lead to lower ethanol use – which is constrained by the mandate – so the consequence is a greater decrease in the ethanol price. In this latter case, the quantity cannot fall. Instead, the mandate compliance costs rise. This effect is not universal; the additional export demand changes the setting from non-binding mandate to binding mandate in only a small number out of the 500 total simulations. The consequence for averages over many simulations, in a greater number of which the link is severed, is that petroleum price changes have a marginally stronger effect on retail prices and on mandate compliance costs, but somewhat less impact on rack prices.

Table 13. Petroleum and natural gas price effects on biofuel market indicators (increased corn export demand).

Absolute effects of changes in petroleum and natural gas prices on indicator variables

	Ethanol prices (dollars per gallon)			Biodiesel prices (dollars per gallon)		Mandate compliance costs (millions of dollars)		
	Retail	Rack, conv.	Rack, cell.	Retail	Plant	Ethanol	Biodiesel	Total
Absolute effect of petrolem price								
same year	0.0101	0.0093	-0.0014	0.0161	0.0027	-52.5	-2.2	-54.7
after 1 year	0.0118	0.0097	0.0000	0.0168	0.0115	-82.7	-6.3	-89.0
after 10 years	0.0110	0.0070	0.0000	0.0165	0.0104	-124.3	-5.8	-130.1
Absolute effect of natural gas price index								
same year	0.0004	0.0004	-0.0002	0.0007	-0.0001	-1.8	-0.6	-2.4
after 1 year	0.0004	0.0005	-0.0001	0.0006	0.0001	-1.9	-0.6	-2.5
after 10 years	0.0004	0.0006	0.0001	0.0003	-0.0003	6.5	-0.6	5.9

Percent changes in indicator variables relative to percent changes in petroleum and natural gas prices

	Ethanol prices			Biodiesel prices		Mandate compliance costs		
	Retail	Rack, conv.	Rack, cell.	Retail	Plant	Ethanol	Biodiesel	Total
Relative effect of a percent change in petroleum price								
same year	0.41	0.42	-0.04	0.52	0.05	-1.70	-0.18	-1.28
after 1 year	0.47	0.44	0.00	0.55	0.22	-2.68	-0.52	-2.08
after 10 years	0.44	0.31	0.00	0.54	0.20	-4.03	-0.48	-3.03
Relative effect of a percent change in natural gas price index								
same year	0.04	0.04	-0.02	0.07	-0.01	-0.16	-0.14	-0.16
after 1 year	0.04	0.06	-0.01	0.05	0.01	-0.17	-0.14	-0.16
after 10 years	0.04	0.08	0.01	0.03	-0.02	0.59	-0.13	0.39

Additional corn export demand has some effects on the links between petroleum and crop prices (Table 14). The parameters associated with the petroleum price suggest that the demand pull on corn price is less strong, as expected, and consequently fewer additional acres are drawn into corn use relative to the base case. The net impact on total crop land is also smaller in this case relative to the base case.

Table 14. Petroleum and natural gas price effects on crop market indicators (increased corn export demand).

Absolute effects of changes in petroleum and natural gas prices on indicator variables

	Crop and crop product prices					Crop area results		
	Corn ($/bu)	Sb. Oil ($/cwt)	Sb. Meal ($/ton)	Wheat ($/bu)	Dist. Gr. ($/ton)	Total (millions of acres)	Corn	Soybean
Absolute effect of petrolem price								
same year	0.009	0.120	0.042	0.005	0.155	-0.005	0.003	-0.005
after 1 year	0.005	0.103	0.058	0.007	0.021	0.011	0.068	-0.037
after 10 years	0.008	0.117	-0.033	0.005	-0.063	0.018	0.117	-0.054
Absolute effect of natural gas price index								
same year	0.000	0.004	-0.007	0.000	0.000	-0.001	-0.001	-0.002
after 1 year	0.001	0.001	0.007	0.001	0.029	-0.004	-0.005	0.006
after 10 years	-0.001	-0.009	-0.142	0.000	-0.020	-0.004	-0.017	0.013

Percent changes in indicator variables relative to percent changes in petroleum and natural gas prices

	Crop and crop product prices					Crop area results		
	Corn	Sb. Oil	Sb. Meal	Wheat	Dist. Gr.	Total	Corn	Soybean
Relative effect of a percent change in petroleum price								
same year	0.21	0.23	0.01	0.08	0.10	0.00	0.00	-0.01
after 1 year	0.12	0.20	0.02	0.11	0.01	0.00	0.06	-0.04
after 10 years	0.17	0.22	-0.01	0.09	-0.04	0.01	0.11	-0.06
Relative effect of a percent change in natural gas price index								
same year	-0.01	0.02	-0.01	-0.01	0.00	0.00	0.00	-0.01
after 1 year	0.03	0.00	0.01	0.03	0.05	0.00	-0.01	0.02
after 10 years	-0.04	-0.05	-0.12	0.00	-0.04	0.00	-0.05	0.04

The base case links between petroleum price and crop prices are changed only slightly if corn export demand is greater, so the eventual effects on such measures of overall sector performance, such as the effects on CCC expenditures, consumers, and farm income, are also changed only slightly (Table 15). The effects are slightly smaller in most cases.

Table 15. Petroleum and natural gas price effects on taxpayers, food consumers, and farmers (increased corn export demand).

Absolute effects of changes in petroleum and natural gas prices on indicator variables

	Government costs	Consumer effects	Farm effects	
	CCC	Expend.	Costs	Net Inc
		(billions of dollars)		
Absolute effect of petrolem price				
same year	0.000	1.537	0.133	-0.064
after 1 year	-0.001	2.189	0.153	0.083
after 10 years	-0.003	2.508	0.268	0.086
Absolute effect of natural gas price index				
same year	0.000	0.099	0.048	-0.043
after 1 year	0.000	0.540	0.068	-0.042
after 10 years	0.000	0.480	0.019	-0.047

Percent changes in indicator variables relative to percent changes in petroleum and natural gas prices

	Government costs	Consumer effects	Farm effects	
	CCC	Expend.	Costs	Net Inc
Relative effect of a percent change in petroleum price				
same year	0.00	0.08	0.03	-0.07
after 1 year	0.00	0.12	0.04	0.09
after 10 years	0.00	0.13	0.07	0.09
Relative effect of a percent change in natural gas price index				
same year	0.00	0.01	0.03	-0.12
after 1 year	0.00	0.08	0.05	-0.12
after 10 years	0.00	0.07	0.01	-0.13

IV. Energy price effects on agricultural production costs

The model representing agricultural and biofuel market interactions that is used in the preceding section is based on several years of development and refinement. Growing biofuel markets and increasingly important biofuel policy decisions led to a growing number of publications on this topic over the last half dozen years. Rising prices of petroleum and other energy commodities is one reason for new improvements in our representation of agricultural production costs. Another reason is the potential that climate policy could also affect production costs directly or through its effects on fuel and electricity prices. In this section, we report new model development to represent how changing energy prices affect agricultural production costs.

Energy prices have important impacts on farm production expenses. Farmers pay directly for diesel fuel and electricity to operate equipment. Energy prices also affect the cost of fertilizer, agricultural chemicals and many other farm inputs.

Some of the effects of energy prices on farm production expenses may appear very straightforward. Higher crude oil prices, for example, would seem to have a fairly predictable effect on the cost to farmers of the fuel they buy. Even in this case, there are a number of complications. Diesel fuel and gasoline prices do not always march in lockstep with crude oil prices, and fixed per-unit fuel taxes mean that a one-percent change in crude oil prices will not necessarily result in a one-percent change in the price farmers pay for the fuel they use. Furthermore, farmers may change production practices in response to changes in fuel prices. If higher fuel prices result in less fuel use, the proportional change in the per-acre cost of fuel will be less than the proportional change in fuel prices.

In other cases, the relationship between energy prices and farm production costs can be far more complex. Natural gas is the main input in manufacturing nitrogen fertilizer, so it seems reasonable to expect that changes in natural gas prices will have a large impact on farm fertilizer expenses. Just how large the impact will be depends not just on the value of the natural gas used to manufacture a unit of nitrogen fertilizer, but also on the response of various actors. For example, a domestic nitrogen fertilizer producer may not be able to pass along all the costs associated with higher domestic natural gas prices if the domestic producer has to compete with offshore producers who do not face the same change in costs. As in the case of fuel, farmers may also adjust fertilizer application rates in response to change in economic incentives.

The model used to generate the 2010 FAPRI-MU baseline estimates farm production expenses as a function of energy prices and other factors that are largely external to the agricultural sector. Price indices for fuel, fertilizer, seed and other major production inputs are specified as functions of price indices for petroleum products, natural gas, electricity, other raw materials, wage rates and interest rates. Some of the parameters were estimated econometrically using time series data; others are set based on assumed technical relationships. Per-acre production expenses were assumed to change proportionally with these input price indices (e.g., a one-percent increase in the fuel price index was assumed to increase per-acre fuel costs by one percent).

This approach has two major limitations. First, the equations are often very simple, typically capturing only one or two of the many factors that affect the price of a particular input. For example, nitrogen fertilizer prices depend on far more factors than just the price of natural gas and the price of refined petroleum products. Wages, electricity rates and other factors would also directly affect the cost of producing nitrogen. In addition, demand factors could also affect nitrogen prices; an increase in corn acreage and prices would increase the demand for nitrogen fertilizer, and would be expected to result in higher nitrogen prices.

Second, assuming that per-acre costs change in the same proportion as input price indices implies that per-acre input usage is fixed. While it may be reasonable to assume that farmers do not make large short-run changes in production practices in response to modest changes in input prices, it is not reasonable to assume no response whatsoever. Also, holding per-acre input usage flat over time implies that per-bushel or per-ton input usage declines over time as per-acre yields increase. Changing technologies often imply declining input usage per unit of output, but there is no particular reason to assume that per-are input usage would remain unchanged over time.

In response to these concerns, a modified version of the baseline model was used to conduct analysis of various scenarios related to hypothetical climate change legislation.[33] The modified model was still very simple, but tried to address at least some of the concerns with the baseline model. Most relevant to this report are two important changes.

First, an effort was made to incorporate energy price impacts wherever they were considered relevant. For example, diesel fuel prices were assumed to impact not just farm fuel costs, but the farm-level price of a variety of production inputs that must be transported to the farms where they are used.

Second, the modified equations assume that producers will adjust input usage in response to changes in input prices. For example, fuel costs per acre change proportionally less than diesel fuel prices, as producers are assumed to slightly reduce fuel use when diesel fuel prices increase.

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[33] See Westhoff, "Impacts of Climate Change Legislation on US Agricultural Markets: Sources of Uncertainty" FAPRI-MU Report #06-10, 2010.

Table 16 shows how the modified model responds to changes in the prices of diesel fuel, natural gas and electricity. Higher diesel fuel prices affect every major corn production cost category, with the largest proportional effect on fuel costs and only small effects on costs for seed, fertilizer and repairs. Overall, a 10 percent increase in diesel fuel prices increases estimated corn operating costs in 2020 by 2.2 percent.

Higher natural gas prices have the largest proportional effect on nitrogen fertilizer prices. Even here, however, the impact is slightly muted by the assumption that competitive pressure from offshore nitrogen producers and slight changes in per-acre application rates would moderate changes in per-acre nitrogen costs. A 10 percent increase in natural gas prices increases estimated corn operating costs in 2020 by 1.1 percent.

Higher electricity prices have modest effects on several cost categories. Given the parameters of the modified model, a 10 percent increase in electricity prices increases 2020 corn operating costs by 0.6 percent. If the prices of all three energy sources (diesel fuel, natural gas and electricity) increase by 10 percent, 2020 corn operating costs increase by 4.0 percent.

Table 16. Impacts of higher energy prices on corn operating costs

	2020 baseline operating costs per acre	Impact of:			
		10% higher diesel fuel price	10% higher natural gas price	10% higher electricity price	10% higher price for all three
		Change from baseline value			
Seed	$91.18	0.9%	0.0%	0.1%	1.0%
Fertilizer	$128.67	1.0%	2.8%	0.8%	4.5%
Nitrogen	$64.33	1.0%	5.0%	1.0%	7.0%
Other	$64.33	1.0%	0.5%	0.5%	2.0%
Chemicals	$33.35	2.0%	1.0%	2.0%	5.0%
Custom operations	$14.41	2.5%	0.0%	0.0%	2.5%
Fuel, lube, and electricity	$51.80	8.5%	0.0%	0.5%	9.0%
Repairs	$19.91	0.5%	0.0%	0.0%	0.5%
Other variable expenses	$0.17	0.2%	0.1%	0.2%	0.5%
Interest on operating capital	$3.95	2.2%	1.1%	0.6%	4.0%
Total, operating costs	$343.44	2.2%	1.1%	0.6%	4.0%

In the modified model, each cost category is assumed to have the same proportional response to changes in energy prices for each of the crops included in the model. Thus, a 10 percent increase in natural gas prices would increase nitrogen fertilizer costs by 5 percent for corn, wheat, cotton, and every other crop.

The mix of cost categories differs significantly across crops, however, so a given change in energy costs will have different proportional effects on per-acre production expenses for different crops. For example, nitrogen fertilizer is a large share of corn production expenses, but is almost irrelevant for soybeans. This helps explain why a 10 percent increase in natural gas prices has a smaller proportional effect on soybean production expenses than it does on corn production expenses (Table 17). When diesel fuel, natural gas and electricity prices all increase by 10 percent, the estimated impact on corn, wheat, cotton and rice operating costs are all between 3.9 percent and 4.6 percent, while the impact on soybean operating costs is just 3.0 percent.

Table 17. Impact of higher energy prices on operating costs for major field crops

	2020 baseline operating costs per acre	Impact of: 10% higher diesel fuel price	10% higher natural gas price	10% higher electricity price	10% higher price for all three
		Change from baseline value			
Corn	$343.44	2.2%	1.1%	0.6%	4.0%
Soybeans	$163.51	2.3%	0.3%	0.5%	3.0%
Wheat	$145.41	2.7%	1.2%	0.6%	4.4%
Upland cotton	$576.78	2.1%	0.5%	1.2%	3.9%
Rice	$590.72	3.5%	0.5%	0.6%	4.6%

The parameters used in the modified model are all based on assumptions that received a limited degree of peer review, but are not based on econometric estimation. Further work continues to improve model specification to better reflect the complex nature of agricultural input markets, and to estimate parameters econometrically where that is feasible and appropriate.

The discussion here has focused on crop sector inputs, but energy prices also affect the cost of various inputs used by livestock producers. The model also includes equations that represent these relationships, but that are not discussed here because of space constraints.

VI. For more information

Related FAPRI-MU publications published, 2008-2010

(See http://www.fapri.missouri.edu/.)

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Kruse, John, Pat Westhoff, Seth Meyer, and Wyatt Thompson. "Economic impacts of not extending biofuel subsidies." *AgBioForum* 10(2): 94-103. 2007.

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Thompson, Wyatt, Seth Meyer, Pat Westhoff. "US biofuel and climate policies duel over cellulosic biomass." Paper presented at the summer meeting of the IATRC. Stuttgart, Germany. 2010.

Donahue, D.J., Seth Meyer, and Wyatt Thompson. "RIN Risks: Using Supply and Demand Behavior to Assess Risk in the Markets for Renewable Identification Numbers used for Renewable Fuel Standard Compliance." Paper presented at the NCCC-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management. St. Louis, Missouri, April 19-20, 2010. (www.farmdoc.illinois.edu/nccc134.)

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