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The Long-Run Impact of Corn-Based Ethanol on the Grain, Oilseed, and Livestock Sectors with Implications for Biotech Crops

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The ongoing growth of corn-based ethanol production raises some fundamental questions about what impact continued growth will have on US and world agriculture. Estimates of the long-run potential for ethanol production can be made by calculating the corn price at which the incentive to expand ethanol production disappears. Under current ethanol tax policy, if the prices of crude oil, natural gas and distillers grains stay at current levels, then the break-even corn price is $4.05 per bushel. A multi-commodity, multi-country system of integrated commodity models is used to estimate the impacts if we ever get to $4.05 corn. At this price, corn-based ethanol production would reach 31.5 billion gallons per year. Supporting this level of production would require 95.6 million acres of corn to be planted. Total corn production would be approximately 15.6 billion bushels, compared to 11.0 billion bushels today. Most of the additional corn acres come from reduced soybean acreage. The demand for biotech corn varieties that allow for continuous corn production would increase dramatically as would the demand for corn, soybean and wheat varieties that can be grown in marginal areas.

Key words: biofuels, commodity markets, corn price, energy markets, ethanol.

Introduction

The recent growth in US ethanol production has been impressive, and there is every indication that this growth will continue. Because commercially viable ethanol facilities require large amounts of corn, the rapid growth in the number of these facilities will have a significant impact on US and world agriculture. To date, there have been limited attempts to use economic tools and models to examine the likely size of the ethanol industry or the impact of this industry on the rest of US and world agriculture.[1]

This analysis makes two contributions. First, we examine the profitability of ethanol production and the incentives for investors to fund these facilities. This examination allows us to calculate the corn price that will cause this expansion to stop. Second, we use a broad model of the world agricultural economy to evaluate the likely impact of US ethanol production on agricultural markets.

1. *Some studies, including Von Lampe (2006), Ferris and Joshi (2005) and Gallagher et al. (2003), have investigated the implications of alternative developments in biofuels markets on world agricultural markets.*

Methodology

Available estimates of total potential energy production from US and international agriculture are typically based on trend-line projections, which in turn are based on ongoing and planned facilities.[2] Most of the work that we are aware of is based on a numeration of current and planned facilities and not on the economic forces that will bring this expansion to a halt. We address the question of how much ethanol will be produced using a different approach. As long as there are profits to be made, investment in ethanol plants will continue. Eventually profits will fall to zero because either the price of ethanol will fall or the price of feedstock will increase. If the determinants of ethanol profitability can be modeled, then we can use the model to estimate the long-run supply curve of ethanol.

The preliminary work presented here is based on the following logic. For any crude oil price, we can calculate the expected market value for unleaded gasoline. We can then find the market price that makes flex-fuel vehicle owners indifferent between using gasoline blended with ethanol and unleaded gasoline. This long-run ethanol price allows us to calculate the corn price that facilities can pay while still covering all costs. We

2. *See, for example, Eidman (2005) and FAPRI (2006).*

assume that investors in ethanol plants will continue to invest until corn prices reach this critical level. Once we know this long-run equilibrium corn price, we can calculate how much corn-based ethanol production it will take to cause corn prices to increase to this (break-even) level.

We first exogenously increase ethanol demand, which induces a higher demand for corn used in ethanol production. This additional corn demand is then introduced into a large-scale model of US and world agriculture until the model suggests a corn price at the critical level. One advantage of the use of this model is that we are also able to evaluate the adjustments in US and world agriculture in response to this new demand for corn.

There are limited numbers of sets of commodity models that have the required multi-commodity international coverage and the cross-commodity inter-linkages to allow for all of the various interactions that are needed for this study. One set of these models is developed and operated by analysts at the Food and Agricultural Policy Research Institute (FAPRI) at Iowa State University and the University of Missouri. We employ modified versions of these models to examine how world agriculture will respond to the set of prices that will cause the agricultural energy sector to stabilize.[3]

Alternative Scenarios

As with all forward-looking analyses, we understand that changes in world events that occur after our work has been completed may limit the accuracy and applicability of this work. Therefore, we have also conducted an analysis of how changes in all of our key parameters (prices of energy and dried distillers grains with solubles, release of Conservation Reserve Program acres and public policy) would alter our results and conclusions.

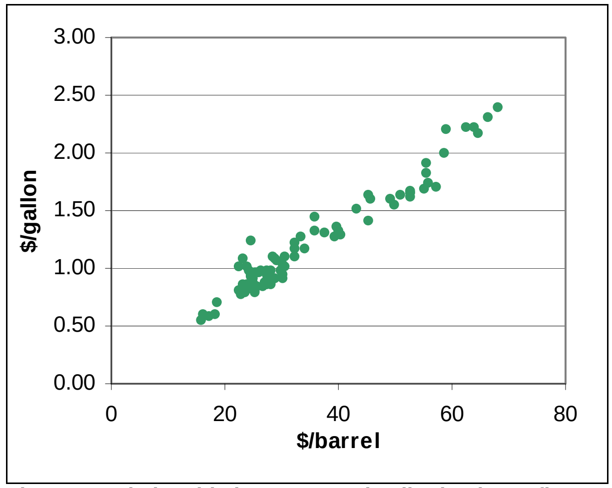

Figure 1. Relationship between crude oil price (US refiner's acquisition cost of imported crude oil) and Omaha wholesale gasoline prices since 2000.

Assumptions

Energy Prices

The critical assumption is that crude oil prices remain at $60 per barrel (as measured by the US unit import price for crude) and we provide a sensitivity analysis for higher and lower crude prices. Figure 1 reveals a proportionate relationship between monthly average Omaha wholesale gasoline prices and monthly average US refiners' acquisition cost of imported crude oil, which represents the world crude oil price. The regression coefficient with a zero intercept is 0.0345, which means that a $60 crude oil price translates into a wholesale gasoline price of $2.07 per gallon. The average basis between the average refinery acquisition price and the settlement price of the New York Mercantile Exchange (NYMEX) futures since 2000 is $4.57. Thus, the $60 per barrel crude price corresponds to a NYMEX price of just under $65.

We assume that ethanol production will eventually become so large that the price of ethanol will be driven only by its energy value, which is 66.67% that of gasoline's energy value. This implies that the energy-equivalent price of ethanol, given a $2.07 per gallon wholesale price for gasoline, is $1.38 per gallon. When the volumetric ethanol excise tax credit (VEETC), a tax credit offered to refiners for blending ethanol with gasoline, of $0.51 per gallon is added to this price, the equivalent wholesale ethanol price increases to $1.89 per gallon. The full amount of the tax credit will be reflected in the corn price assuming competition between blenders is sufficiently high.

3. *The modeling system we use is described at http://www.fapri.iastate.edu/models/. The models implicitly assume that consumers and producers respond to changes in price levels and relative prices in the future as they have been observed to do in the past. The specific models used in this analysis are the CARD international ethanol model, the FAPRI international sugar model and modified or reduced-form versions of the FAPRI US and international crop models. Livestock interactions are maintained within the crop models.*

Of course, to utilize large amounts of ethanol, the United States will need extensive expansion in the number of flex-fuel vehicles in use and a rapid expansion of the ethanol distribution infrastructure. Because this is a long-run analysis, we implicitly assume that the number of flex-fuel vehicles is not a limiting factor.

Operating Costs and Performance

We are looking at a marginal ethanol plant to be built (or not built) at some date in the future. The plant is a 50-million-gallon ethanol plant with an ethanol yield of 3 gallons per bushel and a DDGS (dried distillers grains with solubles) yield of 17 pounds per bushel. We further assume that the price of DDGS remains at the current level of $77.56/ton, providing a credit of $0.66 per bushel of corn used by the plant. We have done an analysis (available on request) where the price of DDGS was allowed to respond to market demand, and this analysis suggests that the price would increase significantly as corn prices increased. This result assumes away the enormous challenges that the ethanol industry is facing as it tries to dispose of, and transport large quantities of, DDGS throughout the world. We assume that operating costs for an ethanol plant are $0.52 per gallon or $1.56 per bushel (F.O. Lichts, 2006), which we assume includes any marketing costs. The proposed plant costs $80 million to build, which, when amortized over 10 years, indicates a capital cost of $0.24 per gallon, or $0.72 per bushel.

Calculating the Long-Run Equilibrium Corn Price

The ethanol plant earns $5.67 for the ethanol produced from one bushel of corn; it also receives $0.66 per bushel for the DDGS co-product. The total cost of processing this bushel is $2.28 ($1.56 for variable costs and $0.72 for fixed costs). We can subtract total costs per bushel from total revenue per bushel to arrive at the break-even price for corn. This equals $6.33 minus $2.28, or $4.05. This means that the plant can pay as much as $4.05 for corn and continue to service all of its fixed and variable costs. We assume that investors in this plant are aware of this calculation and that they will continue to invest as long as they expect the average price of corn delivered to the plant to cost less that this critical amount. The appropriate scenario for this plant is that it is located in Omaha so that the cost of transporting ethanol to an Omaha blender is negligible and the price of corn paid in Omaha is equal to the season-average price of corn in the United States, which is the price of corn used in the model.

One assumption that deserves further discussion involves the wholesale-to-retail markup on ethanol. This markup is composed of transportation cost to the retailer, profit for the retailer and state taxes. If we assume that the ethanol markup in cents per gallon is the same as that for gasoline, then we would implicitly assume that the markup on ethanol is higher when measured in percentage terms. To see why this is so, assume that the gasoline markup is $1 per gallon and that wholesale gasoline also sells for $1 so that the gasoline markup is 100% and retail gasoline prices are $2 per gallon. Assume also that wholesale ethanol sells for its energy value of $0.66 per gallon and that ethanol has a $1 per gallon markup. Note that the ethanol markup is 150% ($1 expressed as a percentage of $0.66) and that the gasoline markup is only 100%.

Given that a large portion of this markup consists of state taxes and that the likely sales area for ethanol will be in the upper Midwestern states where ethanol is politically popular, it seems unlikely that states will charge a higher percentage tax on ethanol than on gasoline. In fact, all of the states that have visited the issue so far have actually worked to impose lower taxes on ethanol than on gasoline.[4] Therefore we have assumed that the

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4. *States that have chosen to impose differential taxes on ethanol and gasoline:*

Iowa*—Effective 07/01/02, motor fuel tax rates will be adjusted annually based on the amounts of ethanol blended gasoline being sold and distributed annually.*

Minnesota*—There is a credit to the wholesaler of 15 cents per gallon of alcohol used to make gasohol.*

Montana*—There is an alcohol distiller credit of 30 cents per gallon of alcohol produced in the state with state agricultural products and used to make gasohol.*

Nebraska*—Rates are variable, adjusted quarterly. The gasoline and gasohol prices include 0.6 cents per gallon. New Nebraska ethanol production facilities may receive an ethanol production credit equal to 18 cents per gallon of ethanol used to fuel motor vehicles.*

North Dakota*—There is a producer credit of 40 cents per gallon of agriculturally derived alcohol produced in the state and used to make gasohol.*

Ohio*—Dealers are refunded 10 cents per gallon of each qualified fuel (ethanol or methanol) blended with unleaded gasoline.*

South Dakota*—There is a credit at the rate of the gasoline tax to distributors blending gasoline with ethanol to product gasohol. There is also a producer incentive payment of 20 cents per gallon.*

Source: http://www.fhwa.dot.gov/ohim/mmfr/jul06/trmfuel.htm.

Table 1. Long-run equilibrium corn prices at various crude oil prices.

Crude oil price ($/barrel)	Gasoline price ($/gallon)	Ethanol price ($/gallon)	Corn price ($/bushel)
With the VEETC			
40	1.38	1.43	2.67
50	1.73	1.66	3.36
60	2.07	1.89	4.05
70	2.42	2.12	4.74
80	2.76	2.35	5.43
Without the VEETC			
40	1.38	0.92	1.14
50	1.73	1.15	1.83
60	2.07	1.38	2.52
70	2.42	1.61	3.21
80	2.76	1.84	3.90

wholesale-to-retail markup on ethanol is the same *in percentage terms* as the markup on gasoline. This may turn out to be conservative given the widespread popularity of ethanol among Midwestern policymakers. The continued use of this assumption means that if ethanol sells at its energy value at retail pumps then it will also be priced at its energy value at the wholesale level.

We realize that in the real world there will be tremendous uncertainty about local corn prices at the time ethanol plants are being built. This suggests that investors will probably be cautious about constructing the last few plants. However, one could also argue that too many plants will be built because the market will overshoot the long-run equilibrium value. In addition, we are ignoring a federal income tax credit of $0.10 per gallon ($0.30 per bushel) on plants with a capacity below 60 million gallons. We also ignore direct state and federal construction subsidies and state and federal tax credits. This assumption is conservative and implicitly provides the investors with a return on the risk they face when investing in a facility that may not start operations for two years.

If our price assumptions are correct, ethanol production will stop growing when corn prices are approximately $4.05. We provide long-run equilibrium corn prices for a wide variety of crude oil prices in Table 1.

To see why this method does not produce a forecast of the future price of corn, consider the following analogy. Assume that pork prices are at $60 per hundred pounds and that production costs are $40 per hundred

Table 2. Long-run equilibrium in the US corn and ethanol markets.

	CARD international ethanol baseline[a]	Estimated long-run solution	Percentage change
Corn price (*$/bushel*)	2.56	4.05	58%
Corn area (*million acres*)	79.4	95.6	21%
Corn production (*million bushels*)	13,040	15,656	20%
Corn use in ethanol (*million bushels*)	3,251	11,103	242%
Ethanol consumption (*million gallons*)	9,476	31,479	232%

[a]*For more details on the baseline numbers, see Elobeid and Tokgoz (2006).*

pounds. Most agricultural economists would predict an expansion in pork production and would calculate the amount of additional pork required to bring the price of pork back to the production cost. In reality, it is likely that high profits in pork production will cause expansion, but it is unlikely that this expansion will stop at just the right time to bring pork prices back to exactly the level of production costs. Note also that there is no real time line with our approach; we are simply interested in the long-run equilibrium price and not in the path that gets us there.

All of the results presented next are based on the analysis just described. This means that they should not be interpreted as predictions or associated with any particular time path.

How Big Will the Ethanol Industry Get?

Our analysis suggests that the US corn-based ethanol industry will continue to expand until the market price of corn reaches $4.05 and after all related markets are in equilibrium. Our next task is to determine how much ethanol production it will take to drive corn prices up to that amount. To accomplish this we added an exogenous demand shock to the existing multi-commodity, multi-country modeling system until the projected market price for corn equaled $4.05. The system allows for interactions across a wide range of commodities and countries. This means that the adjustments required to free corn for the US ethanol industry are felt all over the world. For example, Argentinean corn producers adjust by growing more corn, whereas US and Chinese con-

Table 3. Long-run impact on the US soybean industry.

	CARD international ethanol baseline	Estimated long-run solution	Percentage change
Soybean price (*$/bushel*)	5.52	5.22	-5%
Soybean area (*million acres*)	68.6	59.3	-14%
Soybean production (*million bushels*)	3,014	2,599	-14%
Soybean domestic use (*million bushels*)	2,117	1,850	-13%
Soybean meal price (*$/ton*)	160.2	92.7	-42%
Soybean meal use (*thousand tons*)	37,634	15,179	-60%
Soybean oil price (*$/cwt*)	27.2	32.5	20%

sumers respond by buying less pork. By allowing so many markets to adjust, the model predicts that an enormous amount of corn will become available, as shown in Table 2.

Table 2 shows US corn area increasing by 21% and US ethanol production increasing so that corn use in ethanol production exceeds 11 billion bushels. These adjustments allow the US ethanol industry to expand to 31.5 billion gallons. To put this number into perspective, the United States consumed about 141 billion gallons of gasoline in 2005. This amount of ethanol production far exceeds the capacity of the existing industry as well as forecasts based purely on the number of plants under construction. The only comparable production values are from William Tierney, who tracks ethanol plants that are *planned* and those that are *under construction* (Tierney, 2006). His estimates indicate that if all the plants that are planned are built, then total ethanol production will reach 26 billion gallons by August 2009. Our analysis suggests that if oil prices remain at $60 or more, then most of these planned plants will actually be built. It also suggests that as many as 5 billion gallons of new capacity will be announced and will come online after August 2009.

Impact on Soybean Markets

Although all sectors of world agriculture are expected to adjust as the US ethanol industry expands, the sector most influenced by this expansion is the US soybean sector. High corn prices will provide an incentive to

Table 4. Long-run impact on the US wheat industry.

	CARD international ethanol baseline	Estimated long-run solution	Percentage change
Wheat price (*$/bushel*)	3.80	4.60	20%
Wheat area (*million acres*)	47.7	46.3	-3%
Wheat production (*million bushels*)	2,120	2,052	-3%
Wheat food use (*million bushels*)	935	922	-1%
Wheat feed use (*million bushels*)	150	283	88%
Wheat exports (*million bushels*)	1,043	875	-16%

plant more corn acres, and an expansion of DDGS production will create competition for soybean meal. The results presented in Table 3 show a slightly lower soybean price with higher soybean oil prices being offset by lower soybean meal prices and a 9-million-acre reduction in soybean area. This adjustment can be achieved if approximately half of corn-soybean producers switch from a corn-soybean rotation to a corn-corn-soybean rotation.

These results ignore the positive impact of biodiesel on soybean oil prices and therefore likely overestimate the impact on this sector.[5] The trade-off between corn acres and soybean acres is probably the most suspect part of our analysis. The models we use are based on past behavior, and the predicted relative prices of corn and soybeans are outside of the range of this behavior. It is possible that more soybean acres will come out of production than we indicate here and that soybean prices will be higher than we project. However, it is also possible that biodiesel expansion will allow the soybean industry to limit the soybean area that will switch to corn. If this occurs, then corn prices will rise much quicker, leading to smaller corn-ethanol production than calculated here.

As mentioned, we ran a version of the model in which the price of DDGS was allowed to reflect its feed

5. *A reviewer pointed out that soybean-based biodiesel will not be able to compete against ethanol at any energy value because any increase in energy values that makes soybean oil an attractive input for biodiesel will also provide for a stronger incentive to grow more acres for corn-based ethanol.*

value, and this analysis suggested that DDGS would enter ruminant rations as a displacement for corn with DDGS prices tracking corn prices. If this is true, then the downward pressure on soybean prices mentioned above will not materialize because the rations of non-ruminants will continue to be based on soybean meal.

Impact on Wheat Markets

The impact on US wheat markets is presented in Table 4. The table shows a 20% increase in wheat price and a 3% reduction in wheat area. In terms of wheat domestic use, a significant impact is felt in the feed sector, with feed use increasing from 150 million bushels to 283 million bushels. This higher demand occurs despite the higher wheat price, as less corn is available for feed use and the corn price increase is larger relative to the increase in the wheat price. With higher domestic use, lower production, and higher wheat prices, wheat exports decline by 16%.

Impact on Other Sectors

The US ethanol industry is protected from competition by a 2.5% ad valorem tariff and a specific duty of $0.54 per gallon ($1.62 per bushel equivalent) on imported ethanol.[6] This tariff, coupled with the VEETC, helps separate the US ethanol industry from the rest of the world. Together these interventions will cause the US corn-based ethanol industry to grow at a faster rate than would otherwise have been the case. The increased demand for corn will crowd out US corn exports and allow South American and other corn producers to move into markets that are currently supplied by US corn exports. The model suggests that once the size of the US ethanol industry reaches about 22 billion gallons, the United States will no longer have a surplus of corn to export. This does not mean that current corn-importing countries will face a scarcity of corn. It does, however, mean that they will source their corn from countries such as Argentina, which has the capacity to produce large amounts of additional corn.

The results indicate that corn used for feed by US livestock falls by 33%, from 6 billion bushels in the baseline to 4 billion bushels in the scenario. Some of this adjustment is made possible by an increased use of DDGS, especially in the beef and dairy sectors, and increased use of wheat, hay and pasture. However, part of the reduction will be achieved by reductions in the size of the US pork and poultry industries.

As long as the United States is exporting some corn, US prices will equal the world corn price minus transportations costs. This means that as US corn prices rise, world corn prices will also increase. US livestock producers will experience higher feed costs and this will cause some to exit the industry. This reduced production will cause an increase in market prices, and domestic and international consumers will pay higher prices for US livestock products. The impact on pork and poultry producers will be most severe because these sectors are least able to switch from corn-based diets to DDGS-based diets.[7]

Professor John Lawrence of Iowa State maintains a set of estimated returns for typical Iowa pork producers. His current budgets show a $1.85 per bushel corn cost and a total production cost per head of $101.50. If we increase the corn price from $1.85 to $4.05, this increases corn costs per animal from $27 to $58 and increases total production costs by approximately 31%. US pork production will need to decline by 10 to 15% to allow the industry to pass this cost increase on to the wholesale market.

Sensitivity Analysis

The results in Table 5 show the impact of changes in some key assumptions. The results are most sensitive to changes in the price of crude oil and to the removal of the tax credit that is provided to ethanol blenders. The results are not sensitive to the removal of the import tariff alone, the release of Conservation Reserve Program acres or to changes in the prices of DDGS and natural gas.

Qualifications

We have not examined the impact of weather uncertainty. Were we to introduce the possibility of a drought scenario, then there would not be enough corn to both fuel ethanol plants and to feed livestock herds. High prices would ration available supply in the absence of direct government intervention.

6. *Ethanol from Caribbean Basin Initiative countries is allowed to enter the United States duty free, but the amount is restricted to 60 million gallons or 7% of the US domestic ethanol market, whichever is greater.*

7. *Shurson (2004) has reported that with corn at $2.00 per bushel and soybean meal at $175 per ton, the value of DDGS in rations is as follows: $114.24 for dairy, $100.09 for poultry, $104.66 for layers, $96.34 for swine grower finisher, and $108.00 for beef feedlots.*

Table 5. Impact of various scenarios on US ethanol production and corn feed use.

Scenario	Ethanol production (million gallons)	Corn feed use (million bushels)	Percentage change from long-run solution with $60 crude oil: Ethanol production	Percentage change from long-run solution with $60 crude oil: Corn feed use
$70 crude oil; $4.74 corn price[a]	43,679	3002	40%	-26%
$50 crude oil; $3.36 corn price	19,091	5,009	-39%	24%
No tariff and tax credit; $2.52 corn price	7,148	6,127	-77%	52%
No tariff	30,606	4,047	-2%	0%
Addition of 3 million acres of CRP to corn area	31,220	4,131	0%	2%
DDGS price increases by $10; $4.14 corn price	32,511	3,906	4%	-3%
DDGS price decreases by $10; $3.90 corn price	29,824	4,150	-4%	3%
No corn imports	30,898	3,759	-1%	-7%
20% increase in natural gas price; $3.90 corn price	29,810	4,152	-4%	3%
20% decrease in natural gas price; $4.20 corn price	32,944	3,875	6%	-4%

[a] *All corn prices listed in this table are the energy-equivalent break-even corn prices, given crude oil prices.*

We have also ignored the possibility that high corn prices will stimulate additional research to increase corn yields. The model assumes that trend yields continue to grow at the same rate as in recent years. If it is possible for the seed sector to create and introduce additional varieties before the critical corn price is reached, then the likely size of the ethanol industry will be larger than that shown here and the impacts on other sectors will be less severe. We also have not accounted for the possible development of ethanol production from other cellulosic materials. If and when ethanol production from other cellulosic sources develops, it will affect the size of the impacts outlined in this report.

Impact on Biotech Crops

The results show a very large increase in corn acres at the expense of soybean acres. This suggests that many producers in the traditional Corn Belt will plant corn after corn. Producers have typically rotated corn and soybeans in part to reduce problems associated with pests such as corn rootworm and the European corn borer. Demand for crops that are self-resistant to these insects will increase dramatically. The results also suggest that more corn will be grown in marginal areas. These producers will be interested in corn that is modified to be drought tolerant. The massive amounts of corn acres that will be used for ethanol in concentrated areas around ethanol plants also suggest that many plants will be in a position to utilize and pay a premium for high-starch corn should it ever become profitable to create an economically viable identity preservation system for these varieties.

Who Wins and Who Loses?

Much of the debate surrounding the current incentives to the ethanol sector suggests that these incentives are driven in large part by a desire to reduce US dependence on imported oil. By stimulating the production of ethanol to as much as 20% of total fuel use, these incentive structures appear to be well on their way to meeting this goal.

Other beneficiaries include landowners, who will benefit from a dramatic increase in corn prices and associated increases in land rents. US crop growers will benefit until the higher profits are captured by higher land values and land rents. Dairy and beef producers who are near ethanol plants will benefit from having access to DDGS. Owners of ethanol plants will benefit until corn prices rise to eliminate the current arbitrage in ethanol production.

Specialized pork and poultry producers who do not own shares in ethanol plants will lose, as higher corn prices, and eventually reduced international competitiveness, will cause a reduction in production levels. The transition to these lower production levels will be painful for most of these producers. Ethanol construction will stimulate rural economies, as will the flow of profits from ethanol facilities. However, there will be a reduction in livestock in these same areas and this will eventually work to offset this advantage.

A standard argument in international trade is that while most trade arrangements have winners and losers, the successful agreements are so beneficial to the winners that they create enough surplus to help the losers adjust and adapt. An interesting policy question that we are in the process of addressing is whether the long list of positives associated with the expansion of corn-ethanol production is sufficient to offset the shorter list of negatives.

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