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*Policy Options for Integrated Energy and Agricultural Markets**

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In the past, agricultural markets have been well integrated. Markets for different energy commodities, especially liquid energy products, also have been tightly linked. But agricultural markets and energy markets have not been closely correlated. Table 1 contains partial correlation coefficients between pairwise prices (both levels and first differences) of corn, soybeans, crude oil, gasoline, and ethanol obtained from monthly data for the period 1982–2007. Clearly, the energy pair correlations are quite high ranging from 0.86 to 0.98, while the energy agricultural correlations are quite low, ranging from 0.13 to 0.25. The corn-soybean pair has a correlation of 0.72.

Historically recognizing this market separation, we have evaluated energy and agricultural commodities and policies apart. Can we continue to do that in the future? Until 2002, the fraction of the U.S. corn crop going to ethanol had always been less than 10%. As recently as 2004, it was about 11%. But in 2007, the fraction of the corn crop going to ethanol will be about 22%, double that three years ago—even with about a 25% increase in corn production in 2007. This fraction may exceed 30% in 2008 and it could even approach 40% depending on what happens to corn acreage and production.

Massive production of energy, mainly liquid fuels, from agricultural resources will link agricultural and energy markets tightly (Schmidhuber). The new market integration is perhaps the most fundamentally important change to occur in agriculture in decades. The link between energy and agricultural markets requires an integrated environment to study these markets and design policy alternatives to guide them toward designated goals. This article develops an integrated partial equilibrium framework to analyze economic impacts of four alternative policies that can be implemented in promoting ethanol

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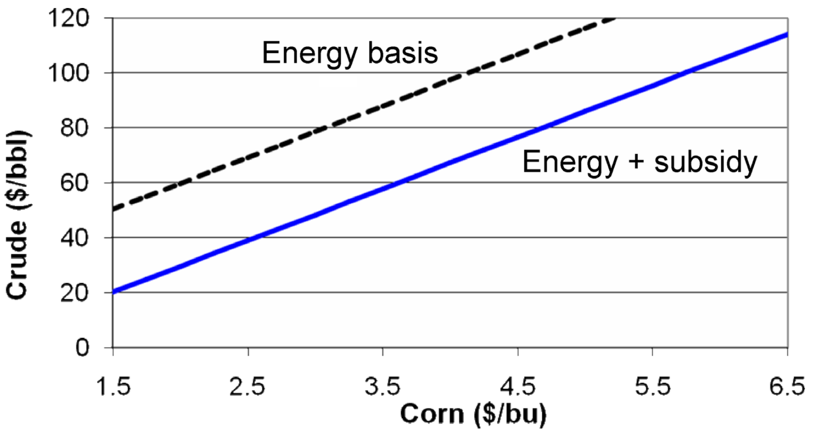
Table 1. Agricultural and energy historic price correlations

Data Pair	Correlation Coefficient (Price Levels)	Correlation Coefficient (First Differences)
Crude-gasoline	0.98	0.65
Crude-ethanol	0.88	0.29
Gasoline-ethanol	0.86	0.35
Ethanol-corn	0.25	0.05
Crude-corn	0.16	−0.11
Crude-soybeans	0.13	−0.01
Corn-soybeans	0.72	0.61

Figure 1. Break-even corn and crude prices with ethanol priced on energy basis with and without federal subsidy



production. These policies are: a fixed subsidy per gallon of ethanol, no subsidy, a variable subsidy linked to the crude oil price, and a renewable fuel standard.

In this article, we first examine combinations of corn-crude oil prices that maintain a representative ethanol producer at the break-even condition (zero economic profit) with and without government supports, in terms of a fixed subsidy (51 cents) per gallon of ethanol produced. Then, we link firm profitability with a partial equilibrium model to analyze the economic impacts of the alternative policies to promote ethanol production under different economic conditions.

Corn-Crude Oil Prices and Ethanol Profitability at a Firm Level

Tyner and Taheripour have examined profitability of a typical ethanol producer with and without the 51 cents ethanol subsidy for different combinations of corn-crude oil prices. Figure 1 depicts these combinations with two break-even lines. The top line in this graph gives the break-even combinations of corn-crude oil prices with no subsidy and the second line

Table 2. Crude oil—corn price break-even points for ethanol production (2007)

Crude Oil ($/bbl)	Energy Basis ($/bu)	Energy Plus Subsidy Basis ($/bu)
20	<0	1.50
40	0.96	2.56
60	2.01	3.62
80	3.08	4.68
100	4.14	5.74
120	5.20	6.81

shows the combinations with 51 cents subsidy. In both cases, ethanol is assumed to be priced on an energy-equivalent basis with gasoline. Table 2 provides the break-even corn prices from the graph for selected oil prices.[1] Several important facts can be deduced from figure 1 and table 2. First, the subsidy adds about $1.60/bushel (bu.) to the break-even price.[2] This shows that the subsidy considerably increases the break-even corn prices. Second, the ethanol industry would not have gotten off the ground without federal subsidies. However, with the subsidy and lower capital and operating costs that existed during that period, ethanol was profitable, but not hugely profitable. The industry grew slowly and steadily over that twenty-year period (Tyner).

Third, with the subsidy and with high oil prices (once gasoline and ethanol pricing follow the long-run pattern), ethanol can be very profitable. The ethanol boom we have experienced is due to this high profitability. The ethanol industry will grow so long as expected oil and corn prices and subsidies indicate profitability. At some point, the increased demand for corn bids up the corn price to the point that it chokes off any additional investment.

Finally, if oil were to fall back to $40, the corn price would have to fall because many of the plants would cease production with lower oil prices and high corn prices. That reduced demand for corn for ethanol would, in turn, lead to a drop in corn prices. Given that we will have about a third of our corn crop in ethanol production, this price drop could be quite large.

So clearly, we are in a new era—one with a tight long-term connection between crude oil and corn prices. Since this tight linkage will exist between crude oil and corn, we can expect it to exist between crude oil and other agricultural commodities as well. To examine and to illustrate these linkages, we have developed a partial equilibrium model incorporating the energy—agriculture linkages among crude oil, gasoline, ethanol, and corn. The next section provides a description of that model. Following that, we present the policy simulations and sensitivity analyses.

Modeling Integrated Markets

Consider two integrated markets of corn and gasoline. The supply side of the corn market consists of identical corn producers. They produce corn using a short-run Cobb-Douglas production function and sell their product in a competitive market. The variable input of corn producers is a composite input that covers all inputs such as seed, fertilizers, chemicals, fuel, electricity, and so on. The demand side of the corn market consists of three users: domestic users that use corn for feed and food purposes; foreign users, and ethanol producers. We model the domestic and foreign demands with constant price elasticity functions. The foreign demand for corn is more elastic than the domestic demand. The demand of the ethanol industry for corn is a function of the demand for ethanol.

The gasoline market has two groups of producers: gasoline and ethanol producers. It is assumed that ethanol is a substitute for gasoline with no additive value. The gasoline and ethanol producers produce according to the short-run Cobb-Douglas production functions. The variable input of gasoline producers is crude oil and the variable input of ethanol producers is corn. Both groups of producers are price takers in product and input markets. We model the demand side with a constant price elasticity demand. The constant parameter of this function can change due to changes in income and population. We assume that the gasoline industry is well established and operates at long-run equilibrium, but the ethanol industry is expanding. The new ethanol producers opt in when there are profits. There is assumed to be no physical or technical limit on ethanol production—only economic limits. The profitability model is taken from Tyner and Taheripour. A more detailed model description is available from the authors.

The model is calibrated to the 2006 data. Elasticities are taken from the existing literature. These parameters are presented in table 3. Endogenous variables are gasoline supply, demand, and price: ethanol supply, demand, and price; corn

Table 3. Major model parameters

Parameter	Value
Own price elasticity of demand for corn for domestic use[1]	−0.1
Own price elasticity for corn for exports[1]	−0.5
Own price elasticity for corn supply[2]	0.4
Own price elasticity for gasoline demand[3]	0.08
Own price elasticity for gasoline supply[4]	0.4
Own price elasticity for ethanol supply[5]	0.1
DDGS price (\$/ton) = 70.12 + 12.57 × price of corn (\$/bu)[6]	
Corn variable costs (\$/bu) = 0.64 + 0.0123 × oil price (\$/bbl)[7]	

[1]In this study we assign −0.1 to the domestic demand elasticity (a bit lower than normal) because we assume that DDGS is a perfect substitute for corn and it covers a portion of the domestic demand for corn. We assigned −0.5 to the elasticity of foreign demand for corn according to the Database for Trade Liberalization Studies (Sullivan, Wainio, and Roningen).
[2]This parameter is based on Westcott and White and Shideed.
[3]This parameter is taken from Hughes, Knittel, and Sperling.
[4]This parameter is taken from Parry and Small.
[5]Several papers have reported or used very inelastic supply functions for ethanol (examples are Miranowski and Rask). We also assigned a small value to the short-run price elasticity of ethanol supply.
[6]This equation is taken from Tyner and Taheripour.
[7]This equation if obtained from a time series for the period of 1975–2006.
DDGS, Dried Distillers Grains with Solubles.

price and production; corn use for ethanol, domestic use, and exports; DDGS supply and price; land used for corn; and the price of the composite input for corn. Exogenous variables include crude oil price, corn yield, ethanol conversion rate, ethanol subsidy level and policy mechanism, and gasoline demand shock (due to nonprice variables such as population and income). The model is driven and solved by market clearing conditions that corn supply equal the sum of corn demands and that ethanol production expands to the point of zero profit. The model is simulated over a range of oil prices and with and without the demand shock. The origin of the demand shock is the Department of Energy (DOE) gasoline demand projection for 2015 compared with 2006 demand. The DOE business forecast, as usual, has gasoline demand increasing 10% by 2015 with little change in oil prices. The no demand shock case essentially assumes that the increased Corporate Average Fuel Economy (CAFE) standards become law such that gasoline demand around 2015–20 is similar to 2006 demand. We simulate the model for crude oil prices ranging between $40 and $120.

For each demand scenario and the entire range of oil prices, we simulate the following policy alternatives:

- Continuation of the current fixed subsidy of 51 cents per gallon of ethanol;
- No ethanol subsidy;
- A variable ethanol subsidy beginning at $70 crude oil and increasing $0.0175 for each $ crude oil falls below $70; and
- A renewable fuel standard (RFS) of 15 billion gallons per year from corn.

In addition to these policy simulations, we also simulate the impact of increased corn yields and increased conversion rate for corn to ethanol.

Simulation Results

There are hundreds of results when one considers all the different assumptions, parameters, oil prices, etc. We restrict our reporting to results on gasoline demand, ethanol production, corn production, fraction of corn used for ethanol, and corn price—all at oil prices ranging from $40 to $120 in $20 increments.

In general, the results conform to expectations and depict well the expected strong linkage in the future between crude oil prices and corn prices and production. While there is no definitive adjustment period included in the model structure, we are generally thinking in terms of about 2020, a common target year in some of the pending legislation. For each of the key results, we will be presenting two cases. The base case is no demand shift; that is, we assume that whatever version of the higher CAFE standards is enacted would leave gasoline consumption at roughly $60 oil (our 2006 base) essentially unchanged unless there is a change in oil price. That is, the higher CAFE standards would essentially offset demand growth due to higher incomes and population. The second case assumes no higher CAFE standards and gasoline demand growth of 10% at roughly constant oil prices. This case assumes, implicitly, that crude oil supply does not continue to keep up with growth in gasoline demand as it has in the past two decades.

Table 4. Ethanol and corn outputs with and without demand shock

	Ethanol Production (BG)					Corn Production (BB)				
Crude Oil Price	**40**	**60**	**80**	**100**	**120**	**40**	**60**	**80**	**100**	**120**
No Demand Shock										
Fixed subsidy	3.3	10.0	13.7	16.0	17.6	10.5	11.5	12.0	12.3	12.5
No subsidy	0.0	0.5	6.5	10.2	12.7	9.9	9.8	10.6	11.2	11.5
Variable subsidy	3.7	4.0	6.5	10.2	12.7	10.6	10.4	10.6	11.2	11.5
RFS	15.0	15.0	15.0	15.0	15.0	12.7	12.4	12.3	12.1	12.0
10% Demand Shock										
Fixed sub	9.7	16.0	19.5	21.7	23.2	11.7	12.6	13.1	13.4	13.6
No subsidy	0.0	8.0	13.4	16.7	19.0	9.9	11.1	11.9	12.4	12.8
Variable subsidy	10.0	10.9	13.4	16.7	19.0	11.7	11.7	11.9	12.4	12.8
RFS	15.0	15.0	15.0	16.7	19.0	12.7	12.4	12.3	12.4	12.8

Gasoline Demand

Gasoline demand elasticity in this model is –0.08 (Hughes, Knittel, and Sperling). Even with this low demand elasticity, for the no demand shock case, gasoline demand varies from roughly 144 billion gallons (BG) per year at $40 oil to about 136 BG at $120 oil, depending on the policy simulation. For the 10% demand shock case, total gasoline demand varies from about 156 BG at $40 to 147 BG at $120. In general, there is not a lot of variation in gasoline demand among the different policy scenarios, which is to be expected.

Ethanol Production

As would be expected, ethanol production varies substantially among the different demand and policy scenarios (table 4). With no demand shock and the current fixed subsidy, ethanol production is 3.3 BG, about the level reached when oil was $40. But at higher oil prices, ethanol production grows considerably to 10 BG for $60 oil and 17.6 BG for $120 oil. With no subsidy, there is no ethanol production until oil reaches $60, which is consistent with our earlier work at the firm level. However, by the time oil reaches $120, ethanol production is 12.7 BG. With the variable subsidy, there is 3.7 BG of ethanol at $40 oil and 4 BG at $60 oil. For higher oil prices, the production levels equal the no subsidy case since there is no subsidy for oil above $70. For the no demand shock case, the RFS level of 15 BG becomes the production level, regardless of the oil price. In other words, the standard is binding at all oil prices. The binding standard imposes an implicit tax on gasoline consumption and provides an implicit subsidy for ethanol producers. Consumers pay the implicit tax at the pump when they buy blended fuel at higher prices. The implicit tax ranges from $1.05/gal. at $40 oil down to $0.23/gal. at $120 oil.

For the 10% demand shock and fixed subsidy case, ethanol ranges from 9.7 BG at $40 oil to 23.2 BG at $120. The demand shock increases gasoline price,

Table 5. Corn price and fraction of corn in ethanol with and without demand shock

	Corn Price ($/bu.)					Fraction of Corn in Ethanol (%)				
Crude Oil Price	**40**	**60**	**80**	**100**	**120**	**40**	**60**	**80**	**100**	**120**
No Demand Shock										
Fixed subsidy	1.97	2.99	3.92	4.81	5.65	11.7	32.3	42.3	48.3	52.4
No subsidy	1.71	1.99	2.90	3.77	4.60	0.0	1.9	22.6	33.9	40.9
Variable subsidy	2.00	2.32	2.90	3.77	4.60	12.9	14.2	22.6	33.9	40.9
RFS	3.15	3.65	4.14	4.61	5.07	43.9	44.7	45.4	46.0	46.5
10% Demand Shock										
Fixed sub	2.56	3.80	4.94	6.01	7.04	30.9	46.9	54.9	59.8	63.2
No subsidy	1.71	2.75	3.87	4.94	5.96	0.0	26.8	41.5	49.8	55.1
Variable subsidy	2.59	3.10	3.87	4.94	5.96	31.7	34.7	41.5	49.8	55.1
RFS	3.15	3.65	4.14	4.94	5.96	43.9	44.7	45.4	49.8	55.1

which, in turn, increases ethanol profitability and production. With no subsidy, there is no ethanol production at $40 oil, but production ranges from 3.9 to 19.0 BG for oil ranging from $50 to $120. With the variable subsidy, ethanol production ranges between 10 and 19 BG over the oil price range. For the RFS, production is at the standard of 15 BG up to $90 oil, but reaches 19 BG with oil at $120. The RFS reaches the same level at the no subsidy and variable subsidy cases because economically, the renewable fuel standard is another mechanism for implementing a variable subsidy. Consumers pay at the pump instead of through their tax bill. The implicit tax is $0.78 at $40 oil and $0.13 at $80 oil. The implicit tax is zero at oil prices above $80 in this case.

Corn Prices

Corn price varies dramatically depending on the oil price in either demand scenario as our hypothesis would predict (table 5). With no demand shock and the fixed subsidy in place, corn varies between $1.97/bu. at $40 oil and $5.65 at $120 oil. With no subsidy, corn price varies between $1.71 at $40 oil and $4.60 at $120 oil. The subsidy clearly has a greater impact on corn price at higher oil prices. With the variable subsidy, corn price ranges between $2.00 and $4.60. The variable subsidy provides a bit more support than the fixed subsidy at the low end, but changes nothing at the high end as there is no subsidy. With the RFS in place, the corn price ranges between $3.15 at $40 oil and $5.07 at $120 oil. With no demand shock, there is an implicit tax at any oil price. The RFS does a far better job of supporting corn price because the implicit ethano subsidy at low oil prices is much higher.

With the demand shock assumption, the results are quite different. With the fixed subsidy, the corn price ranges between $2.56 for $40 oil and $7.04 for $120 oil. Because the demand shock increases the gasoline price, it also increases the ethanol price and therefore induces use of more corn for ethanol and higher corn price. With no subsidy in effect, the range is very different, being $1.71 for $40 oil and $5.96 for $120 oil. However, the point is that if crude oil supply response in the future is less than in the past, demand shocks could have a powerful influence on the ethanol market. With the variable subsidy in effect, the corn price ranges between $2.59 and $5.96, so there is a greater impact on the low end and no impact on the high end as would be expected. With the renewable fuel standard in effect, the corn price ranges between $3.15 for $40 oil and $5.96 for $120 oil. The lower-end price is higher because the implicit subsidy with the RFS in effect is higher than the fixed or variable subsidy. On the upper end, the implicit subsidy with the RFS is zero, so the result is the same as the no subsidy case.

Corn Production

Corn production and acreage respond as might be expected from the above results (table 4). Because of space limitations, we only report corn production in this article. In the no demand shock case with fixed subsidy, corn production ranges between 10.51 billion bushels (BB) at $40 oil and 12.48 BB at $120 oil. With no subsidy, corn production is 9.93 BB at $40 oil and 11.49 BB at $120 oil. Similar to previous cases, with oil at $40, corn supply is 10.57 BB, but at $120 oil, it is the same as the no subsidy case at 11.49 BB. For the variable subsidy case, corn production is pretty flat over the entire range, with production at $40 oil being 10.57 BB and at $120 oil 11.49 BB. Again, this is to be expected, since more stability is one of the major objectives of the variable subsidy. With the renewable fuel standard, corn production is actually slightly higher at $40 oil than at $120 oil because the RFS has a very powerful implicit variable subsidy. Corn production at $40 is 12.68 BB, whereas it is 11.95 BB at $120 oil.

With the 10% demand shock in place, the pattern is similar, but not the absolute numbers. With the fixed subsidy, corn production at $40 oil is 11.67 BB, and it is 13.63 BB at $120 oil. With no subsidy, corn production is 9.93 BB at $40 oil, rising to 12.75 BB at $120 oil. With the variable subsidy, $40 oil yields 11.73 BB of corn, but the upper end remains 12.75 BB. With the RFS and demand shock, corn production is remarkably stable, varying between 12.68 BB at $40 oil and 12.75 BB at $120 oil.

Fraction of Corn Used for Ethanol

The fraction of corn used for ethanol is another important indicator of the results of the different policy alternatives (table 5). In general, as corn use for ethanol increases, it is corn use for exports that declines. There are some declines in domestic use, but exports take the biggest hit. For the no demand shock scenario with the fixed subsidy, corn utilization for ethanol ranges between 12% and 52% as crude oil moves from $40 to $120. With no subsidy in effect, there is no ethanol at $40 oil, but the share of the crop at $120 is 41%. With the variable subsidy, the ethanol share of corn demand ranges between 13% at $40 oil and 41% at $120 oil, a bit more at the lower end and no change at the higher end. With the RFS in effect, the corn share for ethanol is remarkably stable ranging between 44% and 47% over the entire oil price range.

Table 6. Ethanol and corn outputs with and without demand shock with 30% increase in corn yield

	Ethanol Production (BG)					Corn Production (BB)				
Crude Oil Price	**40**	**60**	**80**	**100**	**120**	**40**	**60**	**80**	**100**	**120**
No Demand Shock										
Fixed subsidy	10.9	18.5	22.7	25.3	27.1	12.8	14.0	14.6	14.9	15.2
No subsidy	0.0	6.6	13.6	17.8	20.7	10.9	11.7	12.8	13.4	13.9
Variable subsidy	11.3	10.9	13.6	17.8	20.7	12.9	12.5	12.8	13.4	13.9
RFS	15.0	15.0	15.0	17.8	20.7	13.6	13.3	13.1	13.4	13.9
10% Demand Shock										
Fixed sub	18.5	25.7	29.6	32.1	33.8	14.2	15.4	16.0	16.4	16.6
No subsidy	3.8	15.6	21.8	25.7	28.3	11.5	13.4	14.4	15.0	15.4
Variable subsidy	18.9	19.2	21.8	25.7	28.3	14.3	14.1	14.4	15.0	15.4
RFS	15.0	15.6	21.8	25.7	28.3	13.6	13.4	14.4	15.0	15.4

With the demand shock and fixed subsidy in effect, the corn share for ethanol is 31% for $40 oil and 63% for $120 oil. With no subsidy, there is again no corn used for ethanol at $40 oil but 55% used at $120 oil. With the variable subsidy in effect, the range is from 32% to 55%. With the RFS the corn share begins at 44% for $40 oil, but the peak is 55% for $120—the same level as the no subsidy case because there is no implicit subsidy with the RFS at $120 oil.

Sensitivity Analysis

For this article, due to space limitations, we conduct sensitivity analysis only for a corn yield increase of 30% (tables 6 and 7). Results are reported for the no

Table 7. Corn price and fraction of corn in ethanol with and without demand shock with 30% increase in corn yield

	Corn Price ($/bu)					Fraction of Corn in Ethanol (%)				
Crude Oil Price	**40**	**60**	**80**	**100**	**120**	**40**	**60**	**80**	**100**	**120**
No Demand Shock										
Fixed subsidy	1.67	2.53	3.32	4.06	4.77	31.5	49.1	57.7	62.8	66.2
No subsidy	1.11	1.64	2.39	3.12	3.81	0.00	20.9	39.3	49.3	55.5
Variable subsidy	1.70	1.92	2.39	3.12	3.81	32.7	32.3	39.3	49.3	55.5
RFS	1.93	2.23	2.52	3.12	3.81	41.0	41.9	42.6	49.3	55.5
10% Demand Shock										
Fixed sub	2.18	3.23	4.19	5.10	5.96	48.3	61.9	68.6	72.8	75.6
No subsidy	1.29	2.28	3.22	4.11	4.97	12.1	43.2	56.2	63.4	68.1
Variable subsidy	2.21	2.59	3.22	4.11	4.97	49.0	50.5	56.2	63.4	68.1
RFS	1.93	2.28	3.22	4.11	4.97	41.0	43.2	56.2	63.4	68.1

demand shock and 10% demand shock cases. The results conform to expectations. In all cases, both ethanol production and corn production increase. At $120 oil with no demand shock, for example, with the fixed subsidy, ethanol production reaches 27.1 BG (compared to 17.6 BG in the base case), and corn production reaches 15.2 BB (compared with 12.5 BB in the base case). With the demand shock, the numbers are even larger. For the other policy options, the differences are smaller. Corn price is lower in every case in the yield shock scenario as would be expected. The share of corn going to ethanol tends to be lower for low oil prices compared to the base case and higher when oil prices are higher.

Conclusions

The bottom line from this article is clear—we are entering a new era in which agricultural commodity prices are tied to crude oil prices. This conclusion holds regardless of the policy option in effect (including no subsidy), but the kind of policy being followed has a substantial impact on the size of the impacts. We must incorporate this energy-agriculture linkage in our future policy analyses.

Endnotes

[1]The data in table 2 and figure 1 assume long-term equilibrium pricing relationships between crude oil and gasoline and gasoline and ethanol. In the fourth quarter of 2007, both the crude-gasoline and gasoline-ethanol markets were in disequilibria for different reasons (Tyner, *Bioscience*). However, in due course we can expect them to return to more standard price relationships.

[2]This is higher than the pure volumetric value (about $1.40) because we assume the DDGS price moves with the corn price and natural gas and gasoline (the denaturant) move with oil prices.

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