TRANSITION TO A BIO ECONOMY

Integration of Agricultural and Energy Systems

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Policy Analysis for Integrated Energy and Agricultural Markets in a Partial Equilibrium Framework

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Background

In the past, most agricultural markets have been well integrated. Markets for different energy commodities, especially liquid energy products, also have been tightly linked. However, 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 of 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, energy and agricultural commodities and policies have been evaluated.[2] Can this continue into the future? Until 2002 the fraction of the U.S. corn crop going to ethanol had always been less than 10 percent. As recently as 2004, it was about 11 percent. Yet in 2007, the fraction of the corn crop going to ethanol will be about 22 percent, double that three years ago – even with about a 25 percent increase in corn production in 2007. This fraction may exceed 30 percent in 2008, and it could even approach 40 percent 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, 2007). 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 towards designated goals. This article develops an integrated partial equilibrium framework to analyze economic impacts of four alternative policies which can be implemented in promoting ethanol 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, the combinations of corn-crude oil prices which maintain a representative ethanol producer at the breakeven condition (zero economic profit) with and without government supports, in terms of a fixed subsidy (51 cents) per gallon of ethanol produced are examined. Then firm profitability is linked using 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 (2007) have examined profitability of a typical ethanol producer with and without the 51 cents ethanol subsidy for different combinations of corn-crude prices. Figure 1 depicts these combinations with two breakeven lines.

The top line in this graph gives the breakeven combinations of corn-crude oil prices with no subsidy and the second line 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 breakeven corn prices from the graph for selected oil prices.[3] Several important facts can be deduced from Figure 1 and Table 2. First,

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[2] Several articles have addressed the impacts of higher energy prices on the agricultural cost of production (Dvoskin and Heady, 1976; Christensen *et al*., 1981). These papers do not refer to the link between these markets from the demand side. In this paper, we focus on the link between energy and agriculture from the demand side. In the future, the demand for agricultural commodities (e.g. demand for corn) will be linked to the demand for energy, in particular, for gasoline due the massive production of biofuels from agricultural reserves.

[3] 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 market were in disequilibria for different reasons (Tyne, 2008). However, in due course we can expect then to return to more standard price relationships.

Table 1. Agricultural and Energy Historic Price Correlations Based on Data From 1982 to 2007

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

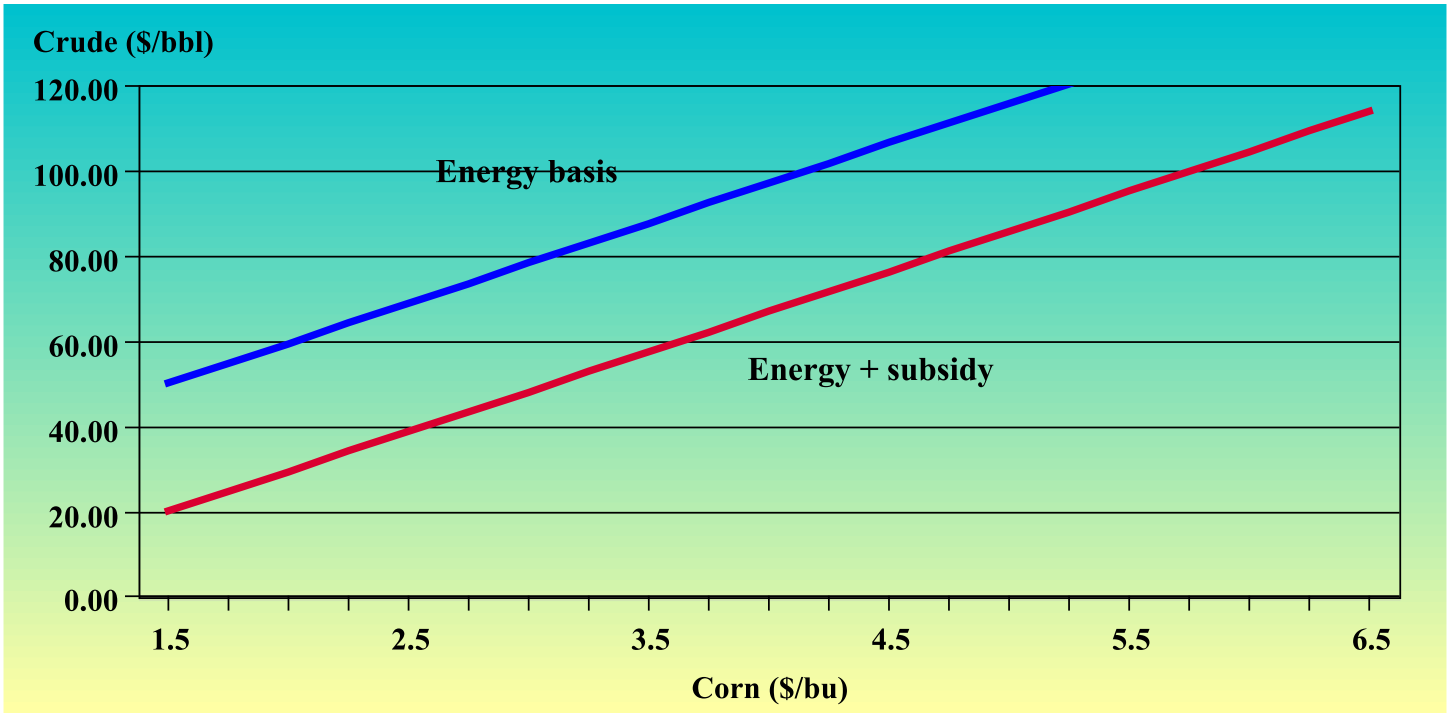

Figure 1. Firm Level Breakeven Combinations of Corn and Crude Oil Prices

Table 2. Crude Oil - Corn Price Breakeven Points for Ethanol Production (2007)

Crude Oil	Energy Basis	Energy Plus Subsidy Basis
($/bbl)	($/bu)	($/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

the subsidy adds about $1.60/bu to the breakeven price.[4] This shows that the subsidy considerably increases the breakeven 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 20 year period (Tyner, 2008).

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

Third, with the subsidy and with high oil prices (once gasoline and ethanol pricing follow the long run pattern), ethanol can be very profitable, such as the ethanol boom experienced in the United States. 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, corn price would have to fall because many of the plants would cease production with lower oil prices and higher corn prices. That reduced demand for corn for ethanol would, in turn, lead to a drop in corn prices. Given that about a third of our corn crop will be used in the production of ethanol, this price drop could be quite large.

Clearly, a new era has arrived – one with a tight long-term connection between crude oil and corn prices. Since this tight linkage will exist between crude oil and corn, it can be expected to exist between crude oil and other agricultural commodities as well. To examine and to illustrate these linkages, a partial equilibrium model was developed incorporating the energy – agriculture linkages between crude, gasoline, ethanol, and corn.

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 constant returns to scale Cobb-Douglas production functions and sell their product in a competitive market. Under these assumptions, an aggregated Cobb-Douglas production function for the whole market is defined. In short-run the variable input of corn producers is a composite input which covers all inputs such as seed, fertilizers, chemicals, fuel, electricity, and so on. In the short run, capital and land are fixed. The demand side of the corn market consists of three users: domestic users which use corn for feed and food purposes, foreign users, and ethanol producers. Domestic and foreign demands are represented using 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. Ethanol is assumed to substitute for gasoline with no additive value. The gasoline and ethanol producers produce according to 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. The demand side is modeled using a constant price elasticity of demand. The constant parameter of this function can change due to changes in income and population. The gasoline industry is assumed to be well established and operates at long run equilibrium, but the ethanol industry is expanding. The new ethanol producers opt in when there are profits. No physical or technical limit on ethanol production is assumed – only economic limits. The profitability model

Table 3. Major Model Parameters

Parameter Description	Value
Own price elasticity of demand for corn for domestic use[a]	-0.1
Own price elasticity for corn for exports[a]	-0.5
Own price elasticity for corn supply[b]	0.4
Own price elasticity for gasoline demand[c]	0.08
Own price elasticity for gasoline supply[d]	0.4
Own price elasticity for ethanol supply[e]	0.1
DDGS price ($/ton) = 70.12 + 12.57 * Price of corn ($/bu)[f]	
Corn variable costs ($/bu) = 0.64 = 0.0123 * oil price ($/bbl)[g]	

[a]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 *et al*., 1989).

[b]This parameter is based on Westcott (1998) and White and Shideed (1991).

[c]This parameter is taken from Hughes, Knittel, and Sperling (2006).

[d]This parameter is taken from Parry and Small (2002).

[e]Several papers have reported or used very inelastic supply functions for ethanol (examples are Miranowski (2007) and Rask (1998)). We also assigned a small value to the short run price elasticity of ethanol supply.

[f]This equation is taken from Tyner and Taheripour (2007).

[g]This equation is obtained from a time series for the period of 1975-2006.

is taken from Tyner and Taheripour (2007). A more detailed model description is provided in Appendix A.

The model is calibrated to 2006 data and then solved using Mathematica (Wolfram, 1999) for several scenarios. 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 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 non-price 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 DOE gasoline demand projection for 2015 compared with 2006 demand. The DOE business as usual forecast has gasoline demand increasing 10% by 2015 with little change in oil prices. The no demand shock case essentially assumes the increased Corporate Average Fuel Economy (CAFE) standards such that gasoline demand around 2015-2020 is similar to 2006 demand. The simulations in this analysis use crude oil prices ranging between $40 and $120.

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

- 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, the impact of increased corn yields and increased conversion rate for corn to ethanol are also simulated.

Simulation Results

As is often the case, there are hundreds of results when one considers all the different assumptions, parameters, oil prices, etc. Due to space limitations, results are restricted to reporting on gasoline demand, ethanol production, corn production, corn price, fraction of corn used for ethanol, exports of corn, and required subsidies – 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, a common target year in some of the pending legislation is the year 2020. For each of the key results, two cases are presented. The base case has no demand shift; hence, the higher CAFE standards are assumed to leave gasoline consumption at roughly $60 oil (our 2006 base) essentially unchanged unless there is a change in oil price. Hence, the higher CAFE standards would essentially offset demand growth due to higher incomes and population. The second case assumes 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.

Gasoline Demand

Gasoline demand elasticity in this model is -0.08 (Hughes, Knittel, and Sperling, 2006). 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 simulated. 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 and Figures 2 and 3). 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. Therefore, there is an implicit tax at all oil 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, which, in turn, increases ethanol profitability and production. With no subsidy, no ethanol is produced at $40 oil, but production ranges

Table 4. Ethanol and Corn Ouputs with and without Gasoline Demand Shock

	Crude Oil Price									
Scenarion and Policy Tool	40	60	80	100	120	40	60	80	100	120
No Demand Shock	Ethanol Production (billion gallons)					Corn Production (billion bushels)				
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 Subsidy	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

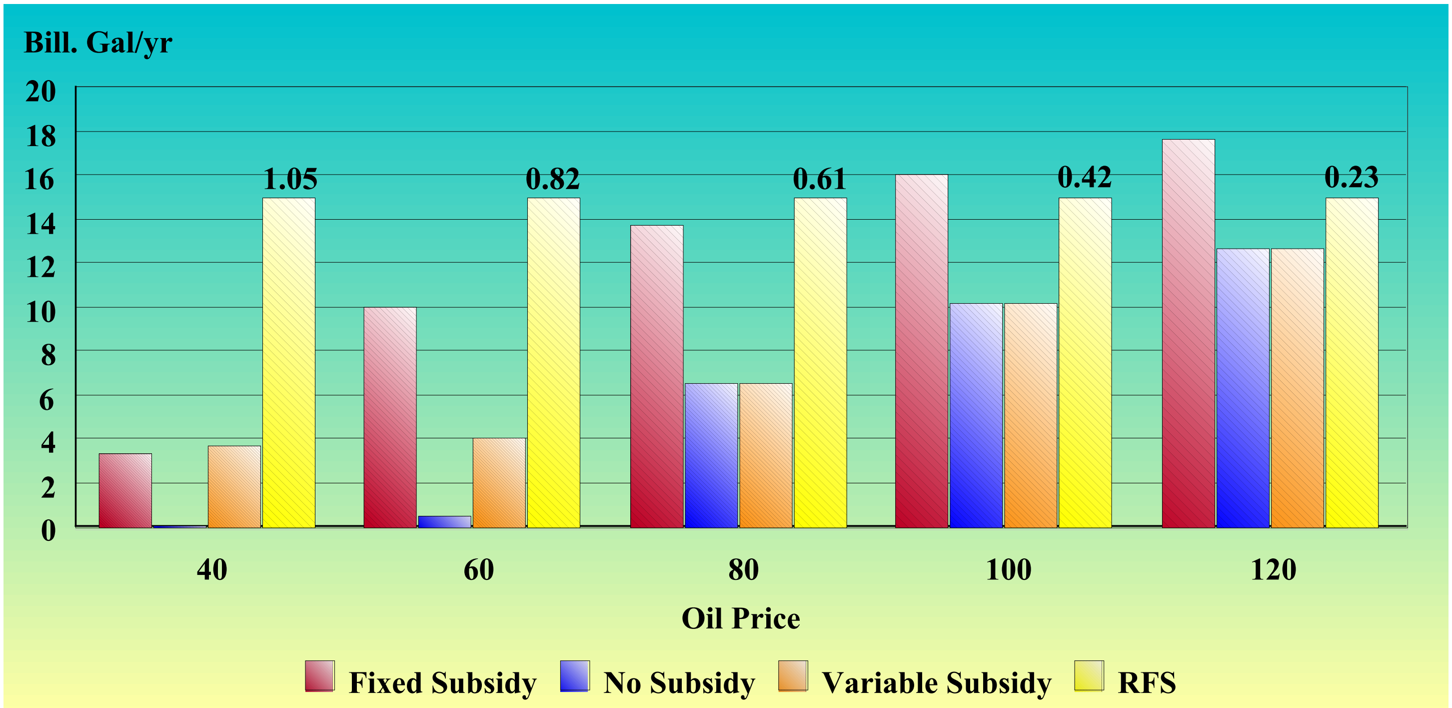

Figure 2. Ethanol Production with No Gasoline Demand Shock

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 in the no subsidy and variable subsidy cases because economically, the renewable fuel standard is another mechanism for implementing a variable incentive. 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 Production

Corn production and acreage respond as might be expected from the above results. Because of space limitations, only corn production in reported in this paper (Table 4 and Figures 4 and 5). In the no demand shock case with fixed subsidy, corn production ranges between 10.51 billion bushels (BB) at $40 oil to 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,

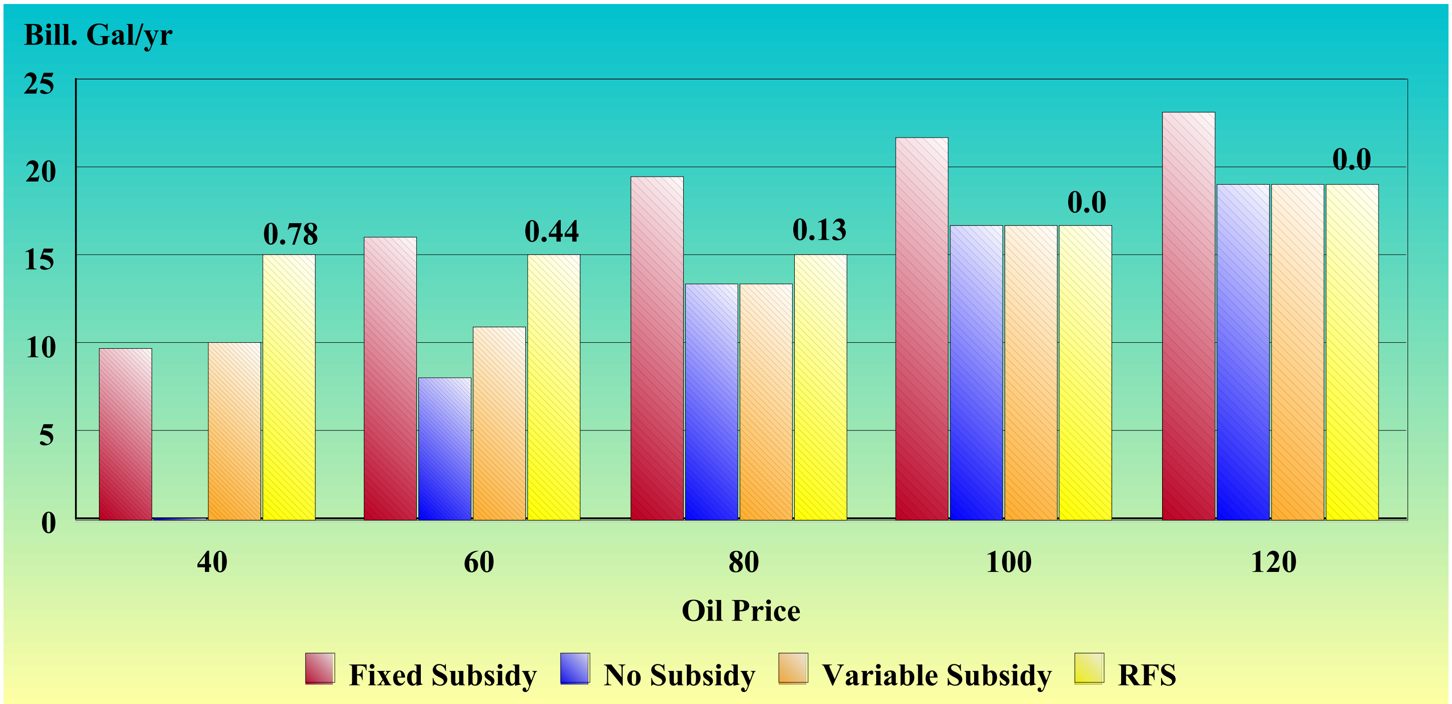

Figure 3. Ethanol Production with 10 Percent Gasoline Demand Shock

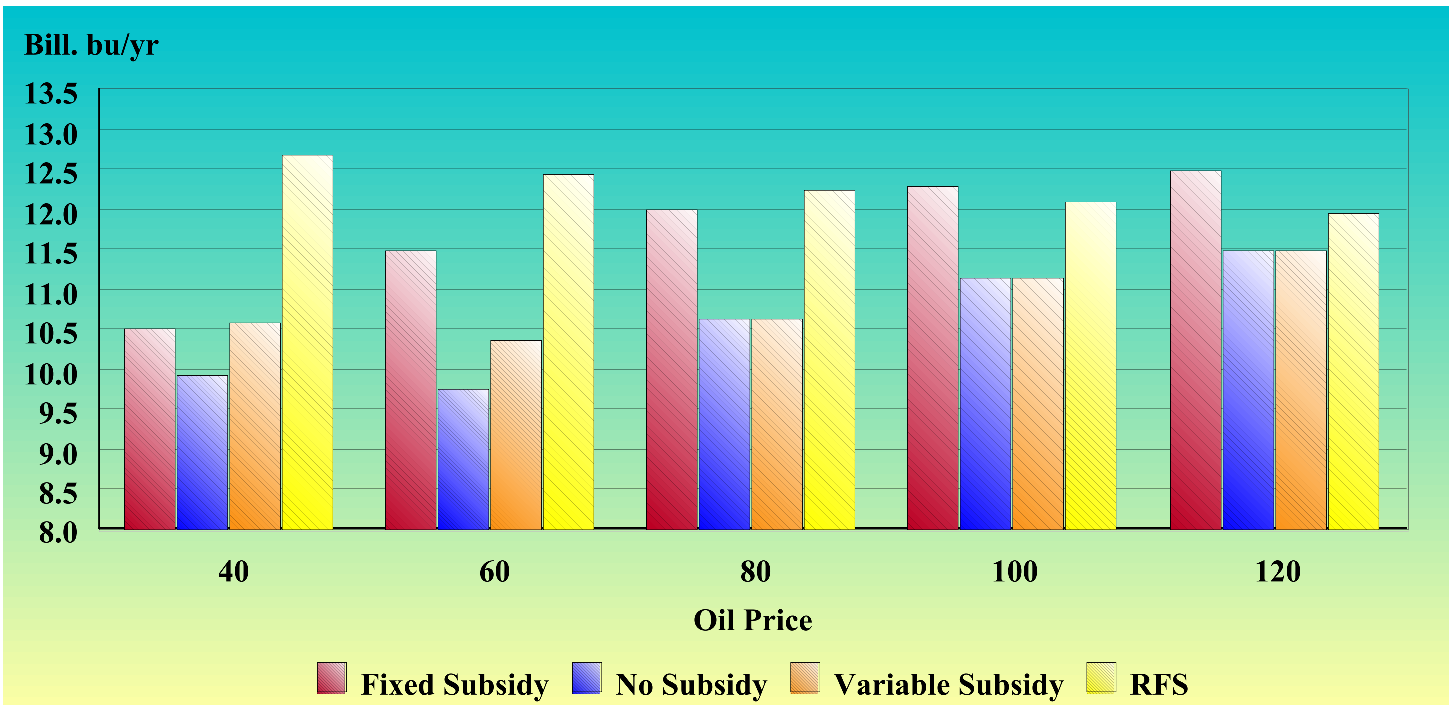

Figure 4. Corn Production with No Gasoline Demand Shock

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 that at $120 oil because corn cost of production increases with crude oil price. 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

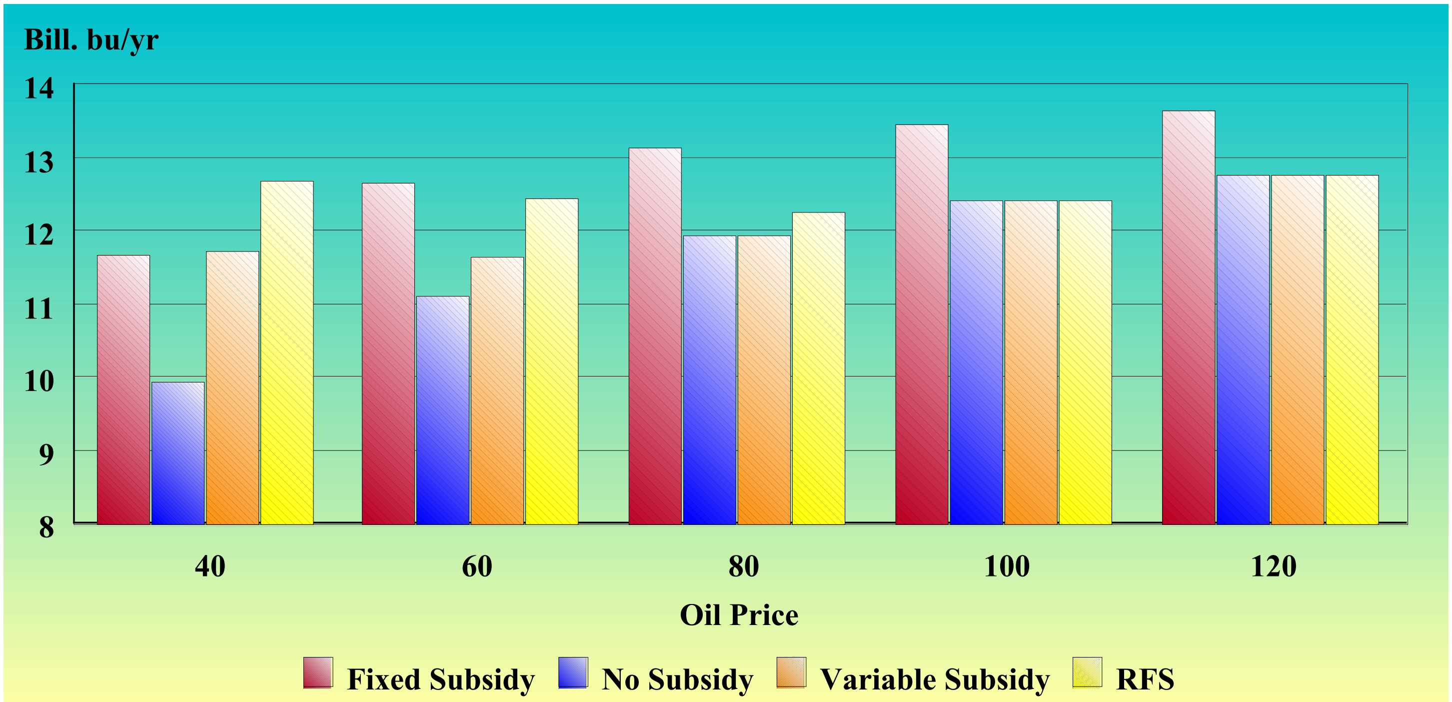

Figure 5. Corn Production with 10 Percent Gasoline Demand Shock

Table 5. Corn Price and Fraction of Corn in Ethanol with and without Gasoline Demand Shock

	Crude Oil Price									
Scenario and Policy Tool	40	60	80	100	120	40	60	80	100	120
No Demand Shock	Corn Price ($/bu)					Fraction of Corn in Ethanol (%)				
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 Subsidy	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

is remarkably stable, varying between 12.68 BB at $40 oil and 12.75 BB at $120 oil.

Corn Prices

Corn price varies dramatically depending on the oil price in either demand scenario as our hypothesis would predict (Table 5 and Figures 6 and 7). With no demand shock and the fixed subsidy in place, corn varies between $1.97/bu at $40 oil to $5.65 at $120 oil. With no subsidy, corn price varies between $1.71 at $40 oil to $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 subsidy at any oil price. The RFS does a far better job of supporting corn price, because the implicit 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

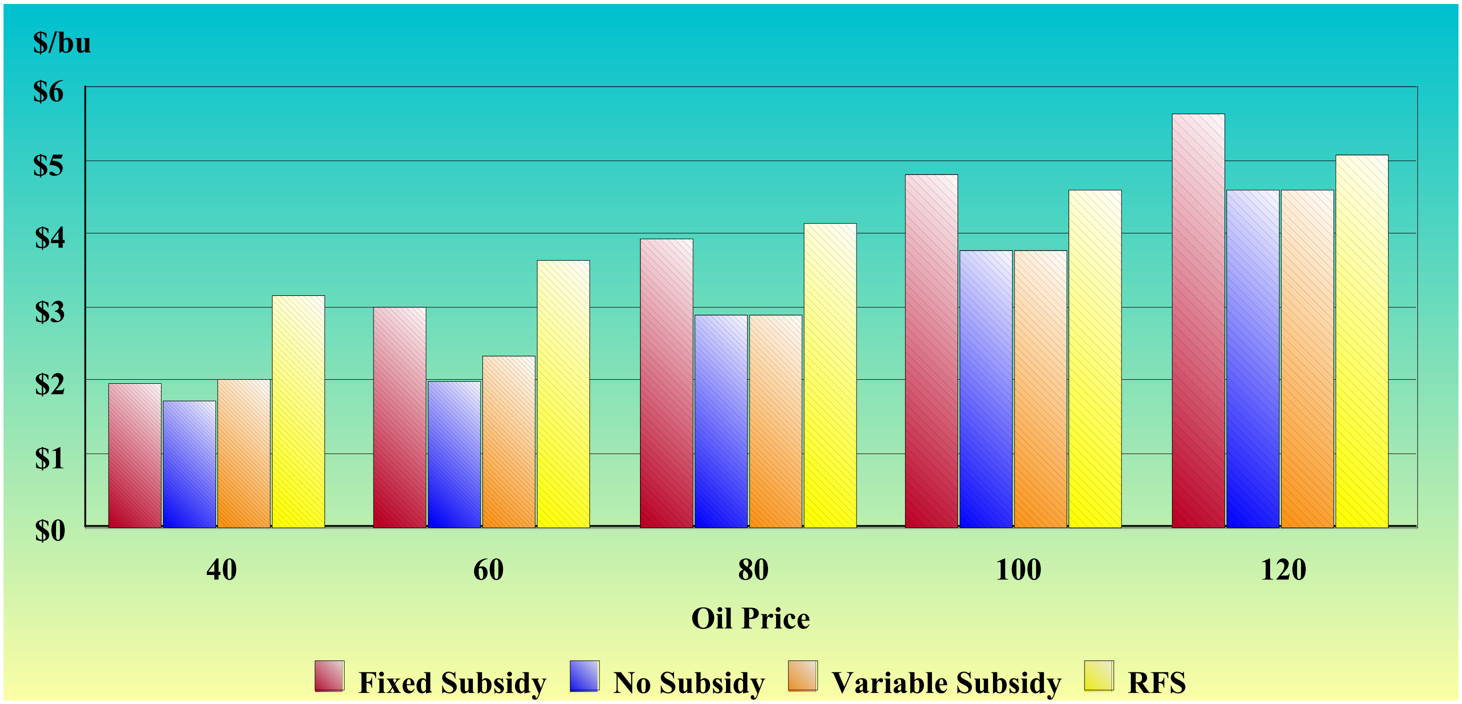

Figure 6. Corn Price with No Gasoline Demand Shock

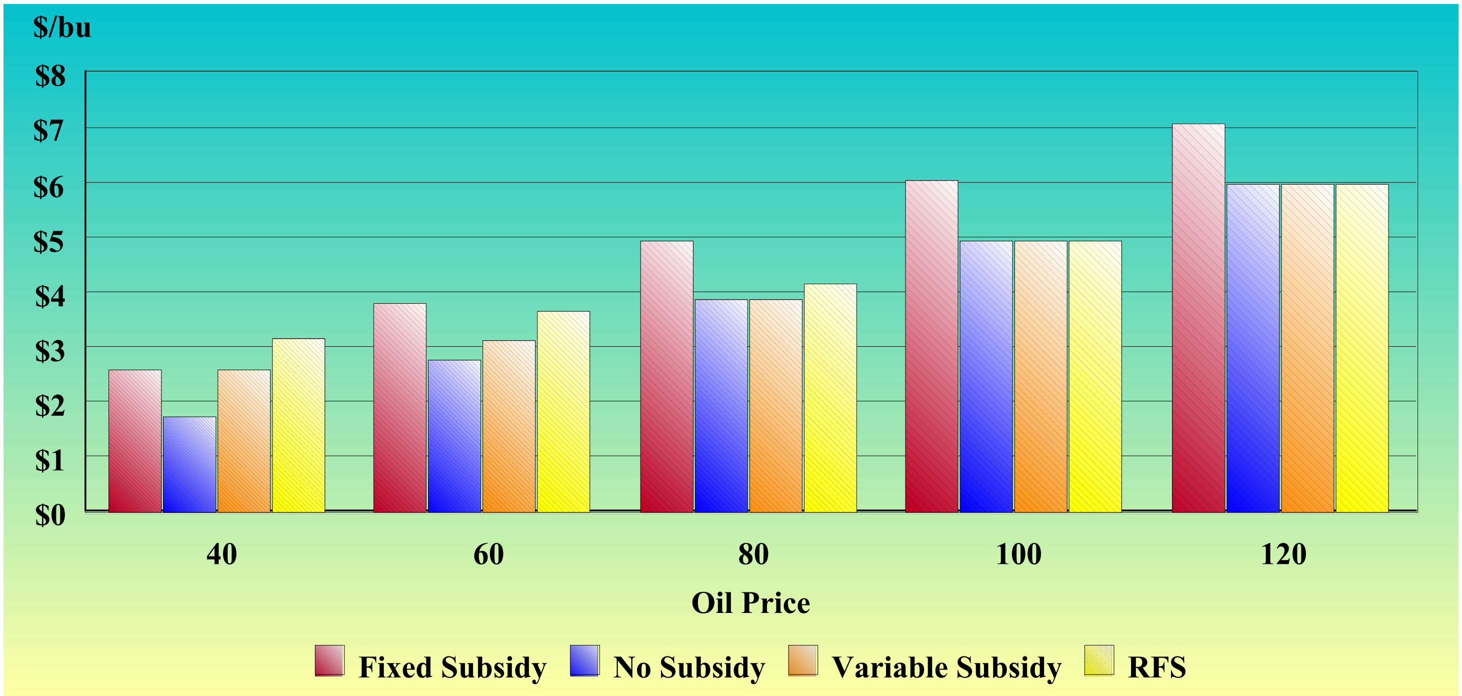

Figure 7. Corn Price with a 10 Percent Gasoline Demand Shock

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 to $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.

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 and Figures 8 and 9). In general, as corn use

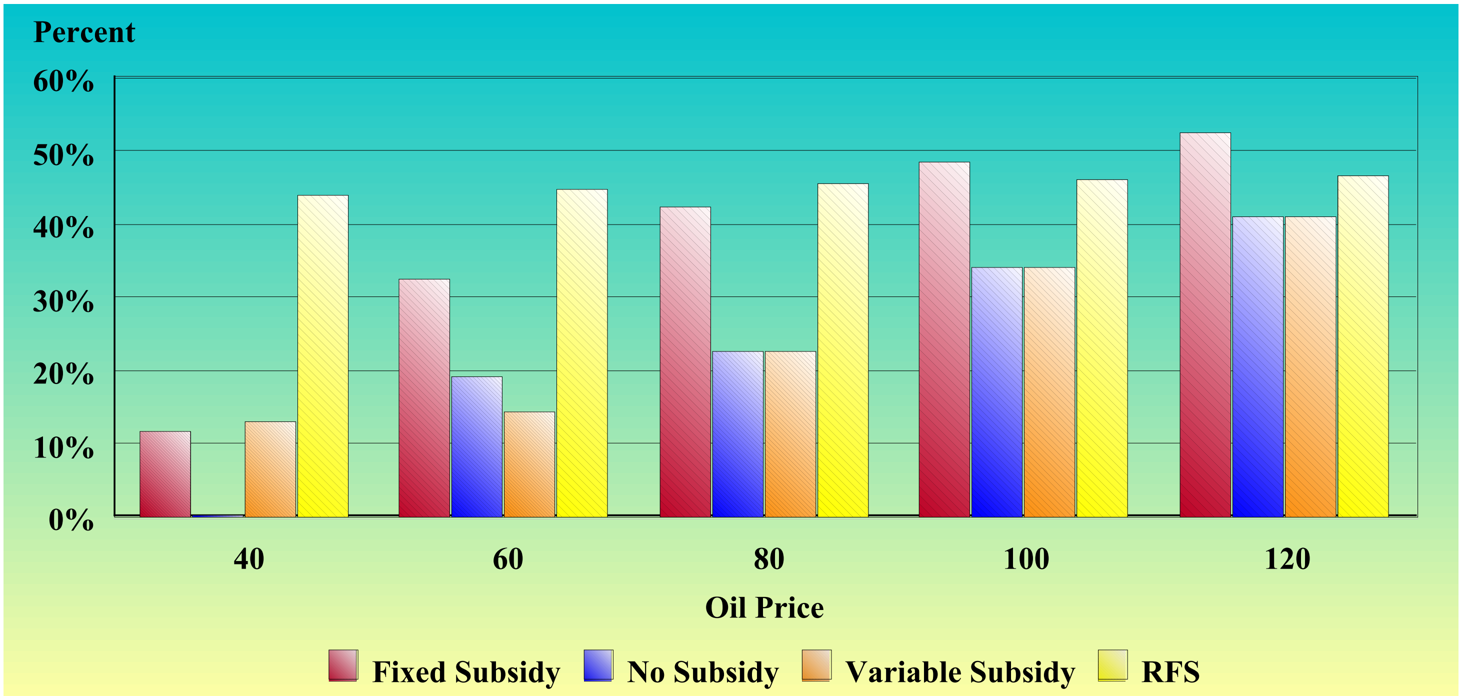

Figure 8. Fraction of Corn for Ethanol with No Gasoline Demand Shock

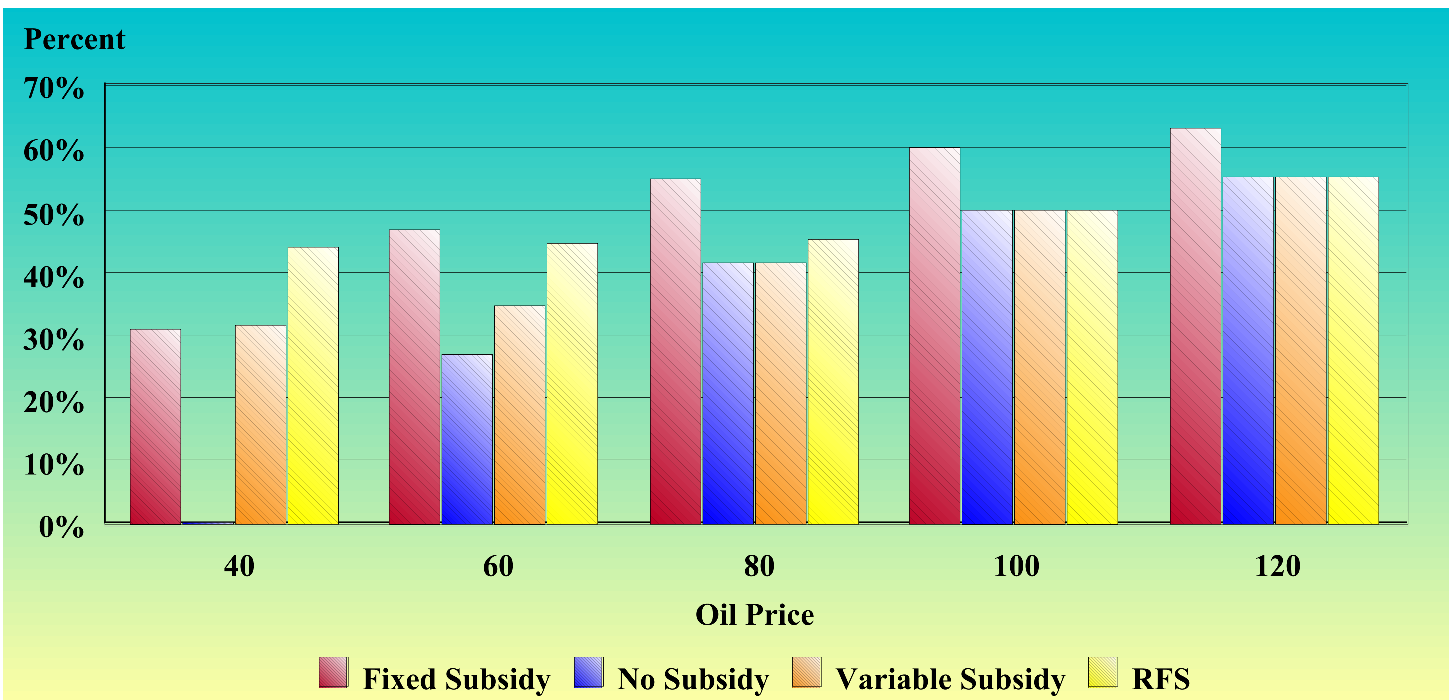

Figure 9. Fraction of Corn for Ethanol with a 10 Percent Gasoline Demand Shock

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.

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 sub-

Table 6. Corn Exports and Policy Costs with and without Gasoline Demand Shock

	Crude Oil Price									
Scenario and Policy Tool	40	60	80	100	120	40	60	80	100	120
No Demand Shock	Corn Exports (billion bushels)					Policy Costs ($ billions)				
Fixed Subsidy	2.46	1.99	1.74	1.57	1.45	1.69	5.10	6.98	8.17	8.99
No Subsidy	2.64	2.44	2.02	1.78	1.61	0.00	0.00	0.00	0.00	0.00
Variable Subsidy	2.44	2.26	2.02	1.78	1.61	1.93	0.69	0.00	0.00	0.00
RFS	1.94	1.80	1.69	1.60	1.53	15.77	12.31	9.18	6.25	3.49
10% Demand Shock										
Fixed Subsidy	2.15	1.77	1.55	1.41	1.30	4.96	8.16	9.93	11.06	11.84
No Subsidy	2.64	2.08	1.75	1.55	1.41	0.00	0.00	0.00	0.00	0.00
Variable Subsidy	2.14	1.96	1.75	1.55	1.41	5.27	1.91	0.00	0.00	0.00
RFS	1.94	1.80	1.69	1.55	1.41	11.70	6.63	1.96	0.00	0.00

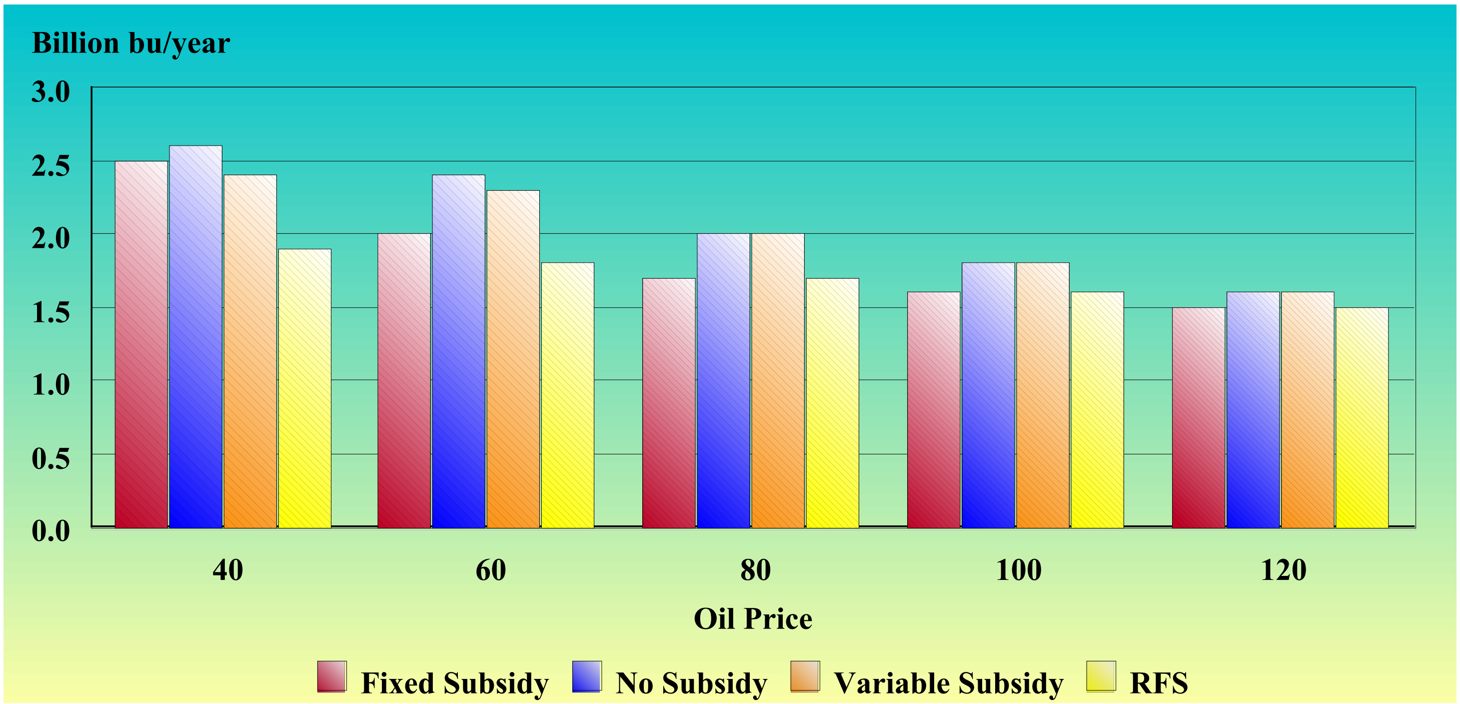

Figure 10. Corn Exports with No Gasoline Demand Shock

sidy in effect, the range is 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.

Corn Exports

Corn exports fall due to more production of ethanol under all policy options when the crude oil price goes up for both cases of no demand shock and 10% demand shock (Table 6 and Figures 10 and 11). In general the RFS and fixed subsidy cause more reduction in corn exports, because these policies stimulate the ethanol market more than the no subsidy and variable subsidy policies. Under the fixed subsidy, corn exports fall from 2.46 BB to 1.45 BB when the crude oil price goes up from $40 to $120 per barrel with no demand shock. Under this policy, corn exports fall from 2.15 BB to 1.3 BB for the same crude oil price change with a 10% demand shock. Under the RFS, corn exports fall from 1.94 BB to 1.53 BB when the crude oil price goes up from $40 to $120 with no demand shock. With the demand shock corn exports fall from 1.94 BB to 1.41 BB under the RFS. In this analysis, it is assumed that the price elasticity of foreign demand for corn is 0.5. If the corn export demand were more elastic, corn exports would fall more.

Policy Costs

Finally, government or consumer costs needed to implement the alternative policies are presented (Table 6 and Fig-

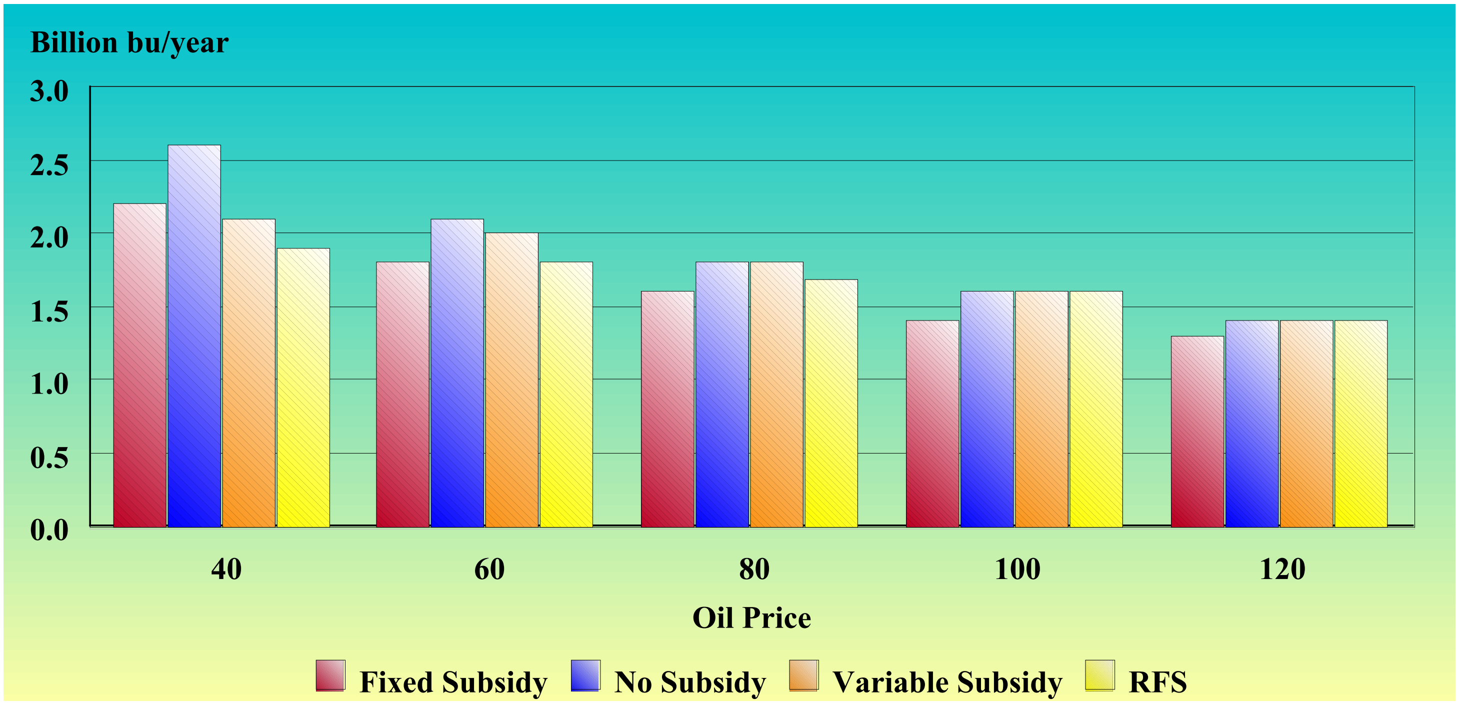

Figure 11. Corn Exports with a 10 Percent Gasoline Demand Shock

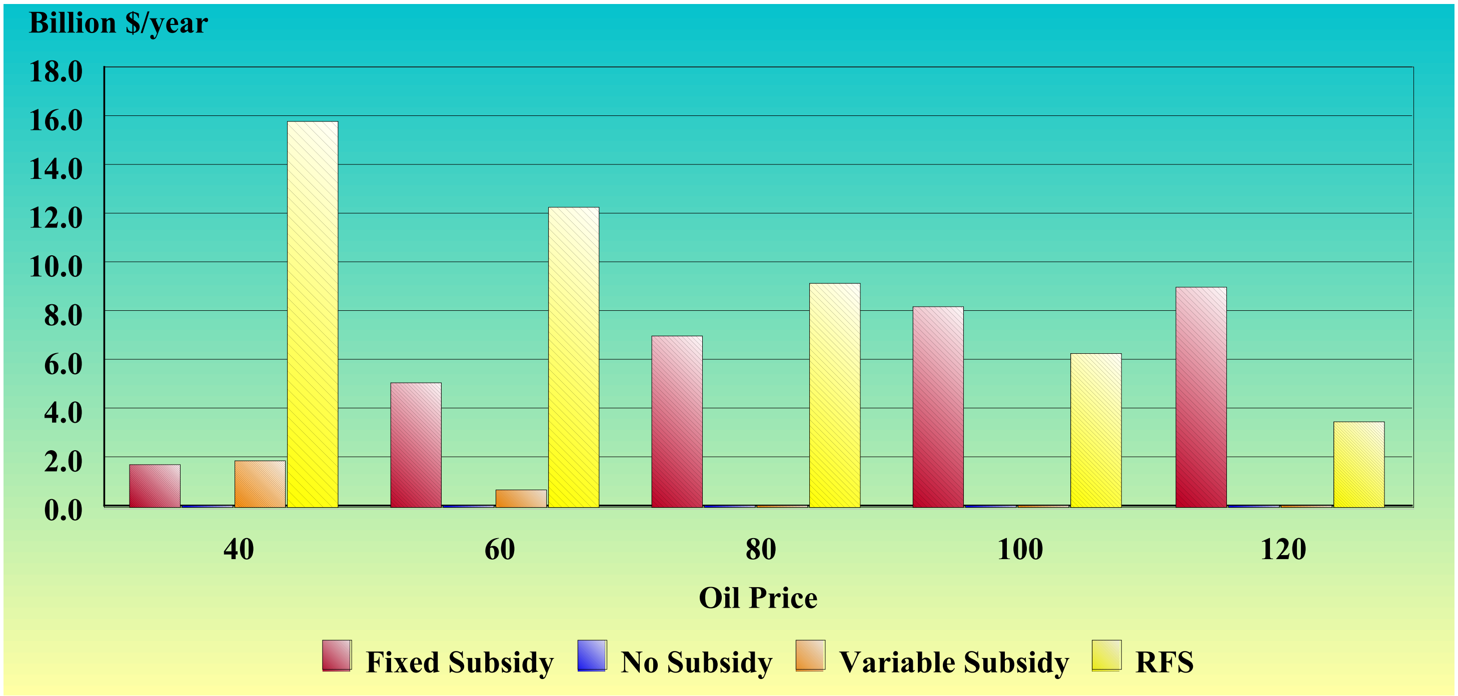

Figure 12. Policy Costs with No Gasoline Demand Shock

ures 12 and 13). Of course, the no subsidy policy has no cost either for consumers or government. The fixed subsidy has high government budget costs. With no demand shock, subsidies paid by the government go up from $1.69 to $8.99 billion when the crude oil price goes up from $40 to $120 per barrel under the fixed subsidy policy. With a 10 percent demand shock the subsidy goes up from $4.96 to $11.84 billion under this policy. The variable subsidy policy only causes financial burden for low prices of crude oil. For example, when the crude oil price is $40 per barrel, required subsidies are $1.93 and $5.27 billion with no demand shock and a 10% demand shock, respectively. The RFS policy has no financial burden for the government, but it increases the fuel cost for consumers through an implicit tax. For example, when the crude oil price is $40 per barrel, the implicit tax costs are $15.77 and $11.7 billion with no demand shock and a 10% demand shock, respectively. The implicit tax falls as oil price increases.

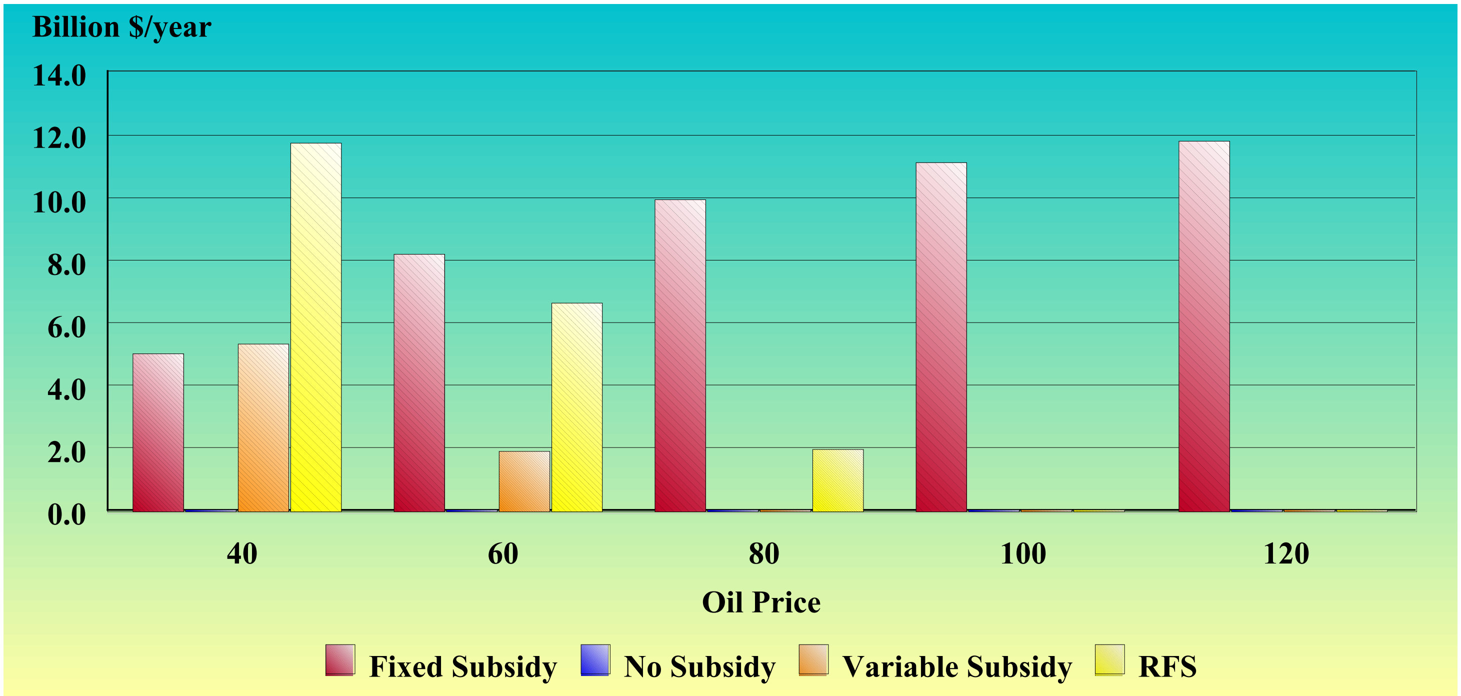

Figure 13. Policy Costs with a 10 Percent Gasoline Demand Shock

The average policy cost over all oil prices is quite sensitive to the presence or absence of a demand shock. With no demand shock, the fixed subsidy cost averages $6.2 billion, and the RFS $9.4 billion annually. However, with the demand shock, the fixed subsidy costs $9.2 billion, and the RFS $4.1 billion. Thus, the greater the demand stimulus, the greater the advantage of RFS over the fixed subsidy. The variable subsidy average cost is quite low under either demand scenario.

Sensitivity Analysis

For this paper, a sensitivity analysis is conducted for a corn yield increase of 30% (Tables 7 and 8). Results are reported for the no 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

Large differences in costs occur among the policy alternatives. Government officials will have to weigh the trade-

Table 7. Ethanol and Corn Outputs with and without Gasoline Demand Shock with 30% Increase in Corn Yield

	Crude Oil Price									
Scenario and Policy Tool	40	60	80	100	120	40	60	80	100	120
No Demand Shock	Ethanol Production (billion gallons)					Corn Production (billion bushels)				
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 Subsidy	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

Table 8. Corn Price and Fraction of Corn in Ethanol with and without Gasoline Demand Shock with 30% Increase in Corn Yield

Scenario and Policy Tool	Crude Oil Price									
	40	60	80	100	120	40	60	80	100	120
No Demand Shock	Corn Price ($/bu)					Fraction of Corn in Ethanol (%)				
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 Subsidy	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

offs between perceived benefits and costs of each of the alternatives.

At high oil prices, the differences among the policy alternatives are smaller with the oil price playing the dominant role in influencing corn price and production as well as ethanol price and production.

The bottom line from this paper is clear – a new era has arrived 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. This energy – agriculture linkage must be incorporated in our future policy analyses.

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Appendix A

Model Description

This Appendix explains the main components of the model used in this paper. First, the demand and supply sides of the corn and gasoline markets are explained. Then DDGS is introduced as a substitute for corn in the corn market. Finally, market clearing conditions are defined and other equations used in the model are introduced.

Corn Market

Demand side

The demand side consists of three major corn users:

Foreign users (corn demand for exports, q_{cxd}),

Domestic uses for food and feed (corn demand for food and feed, q_{ccd}), and

Ethanol industry (corn demand for ethanol, q_{ced}).

Foreign and domestic demands for corn are functions of the corn price, p_c, with the following functional forms:

$q_{cxd} = {}^{A}cxd/p_c^{\,cxa}$, and

$q_{cdd} = {}^{A}cdd/p_c^{\,cda}$.

Here *cxa* and *cda* are own price elasticities of the demands for exports and domestic uses for food and feed. In these demands functions, A_{cxd} and A_{cdd} are constant parameters in short run, but they can change in the long run. The demand of the ethanol industry for corn will be equal to:

$q_{ced} = y.q_{se}$.

Here y is the corn-ethanol conversion factor and q_{se} is the quantity of supply of ethanol.

Finally, the total corn demand is equal to:

$q_{cd} = q_{cxd} + q_{cdd} + q_{ced}$.

Supply side

A Cobb-Douglas production function is used for a representative corn producer to estimate the supply side of the corn market:

$q_{cs} = AK^{\theta 1}L^{\theta 2}R^{\theta 3}F^{\theta 4}$.

Here q_{cs} represents quantity of corn and A is a constant parameter. In this production function, K, L, and R stand for capital, labor, and land, respectively. Here, F is an aggregated input and represents inputs such as fertilizer, pesticides, seeds energy, and other variable inputs. Parameters θ_1, θ_2, θ_3, and θ_4 show elasticities of output with respect to changes in inputs. All inputs, except F, are constant in the short-run and that $\sum\theta_i = 1$. According to these assumptions the following short run corn production function can be defined:

$q_{cs} = M.F^{\theta 4}$,

where $M = AK^{\theta 1}L^{\theta 2}R^{\theta 3}$. This short run production function is used to define the following short run profit function:

$\pi = p_C(M.F^{\theta 4}) - p_F F$.

Here, p_F is the price of the composite input F. The corn producer determines the optimal level of F to maximize its profit. From the first order condition of the profit maximization problem, the optimal level of F would be equal to:

$p_F = (p_F/\theta_4.p_C.M)^{1/\theta 4-1}$.

The optimal level of F is substituted into the short run production function to derive the following short run supply function for corn:

$q_{cs} = A_{CS}(p_C)^{CS\beta}(p_F)^{-CS\beta}$.

In this supply function $A_{CS} = M(1/\theta_4.M)^{\theta 4/\theta 4-1}$ and $-\theta_4/\theta_4$-1. In this supply function, $CS\beta$ is the own price elasticity of corn with respect to its price. This elasticity is positive because $\theta_4 < 1$. Note that the parameter A_{CS} is constant in the short run but it can change due to changes in capital, labor, and land in long run.

Gasoline Market

Demand side

The following functional form for the gasoline demand is considered:

$q_{gd} = {}^{A}gd/p_g^{\,ga}$.

Here q_{gd} is the quantity of demand for gasoline, *ga* is its own price elasticity, and p_g is the price of gasoline. In this function A_{gd} is constant in the short run, but it can change in the long run. In particular, it can grow with income and population, and decline with energy efficiency improvement.

Supply side

The supply side of this market consists of gasoline producers and ethanol producers. Methods to define the supply of corn are used to define short run supply functions for gasoline and ethanol. Gasoline producers produce gasoline from crude oil. The supply of gasoline is a function of its price and the price of crude oil according to following functional form:

$q_{gos} = A_{gos}(p_g)^{gs\beta}(p_o)^{-gs\beta}$.

Here q_{gos} is the quantity of gasoline produced from crude oil, $gs\beta$ is the own price elasticity of supply of gasoline with respect to its price, and p_o is the crude oil price. In this supply function A_{gos} is a constant parameter in the short run, but it can change in the long run due to changes in capital, labor, and other inputs.

Ethanol producers produce ethanol from corn. The supply of ethanol is a function of its price and the price of corn according to following functional form:

$q_{es} = A_{es}(p_e)^{es\beta}(p_c)^{-es\beta}$.

Here q_{es} is the quantity of supply of ethanol produced from corn, $es\beta$ is the own price elasticity of supply of ethanol with respect to its price, and p_c is the corn price. In this function A_{es} is a constant parameter in the short run, but it can change in the long run. In particular, this parameter increases with new investment in ethanol industry.

Each gallon of ethanol is assumed to contain 70% energy of a gallon of gasoline. Hence total supply of gasoline is equal to:

$q_{gs} = q_{gos} + 0.7*q_{es}$.

DDGS as a Substitute for Corn

DDGS is a byproduct of ethanol industry. This byproduct plays two important roles. It is a substitute for corn in livestock industry. Therefore, to some extent, it can mitigate impacts of ethanol production on the corn market. On the other hand it enhances profitability of ethanol industry. In particular, if the price of DDGS goes up with the corn price, it helps ethanol producers to maintain their profitability when the corn price goes up. For these reasons, it is assumed DDGS is a substitute for corn and covers a portion of corn demand. The production of DDGS is determined according to the following relationship:

$$q_{DDGS} = \gamma . q_{ced} .$$

Here q_{DDGS} is the quantity of produced DDGS and γ is the corn-DDGS conversion factor.

Market Clearing Conditions

The market clearing conditions are defined by the following relationships:

$$q_{cs} = q_{cxd} + (q_{cdd} - q_{DDGS}) + q_{ced} \text{, and}$$

$$q_{gs} = q_{gd} .$$

The first relationship represents the corn market clearing condition. In this relationship it is assume that DDGS is perfect substitute for the domestic use of corn. The second relationship represents the gasoline market clearing condition. In the second equation it is assumed that gasoline and ethanol (adjusted for the energy content) are perfect substitute.

Expansion of Ethanol Industry

The ethanol industry is currently experiencing a gold rush period. Expansion is assumed to continue until a zero profit condition is reached. Profits per gallon of ethanol are estimated according to the following relationship:

$$\pi = (0.7p_g.q_{es} + p_{DDGS}.q_{DDGS} - p_c.q_{ced} - oc.q_{es})/q_{es} .$$

All variables in the above equation are defined earlier except *oc*. This variable represents non-corn costs per gallon of ethanol. In the base year *oc* is et equal to = *\$0.99* according to Tyner and Taheripour (2007) and that *oc* increases slightly with the crude oil price. In addition, it is assumed that the ethanol industry will expand to reach $\pi=0$ in long run.

Other Equations

The operating costs of producing corn are assigned to variable *F* and p_F is defined as the costs of producing corn per bushel of corn. p_F is function of crude oil price and a linear relationship is established between these two variables according to the following equation:

$$p_F = a + bp_o$$

The parameters of this equation are estimated according to annual time series from 1975 to 2006. The estimated equation is:

$$p_F = 0.64 + 0.0123p_o \qquad R^2 = 0.45$$

↓ ↓

$t = 10.11 \qquad t = 4.95$

Here, p_F is measured in \$/bushel and the price of crude oil is measures in \$/barrel. The price of DDGS is determined with the following linear equation according to Tyner and Taheripour (2007):

$$p_{DDGS}(\$/ton) = 70.12 + 12.57p_c(\$/bushel).$$