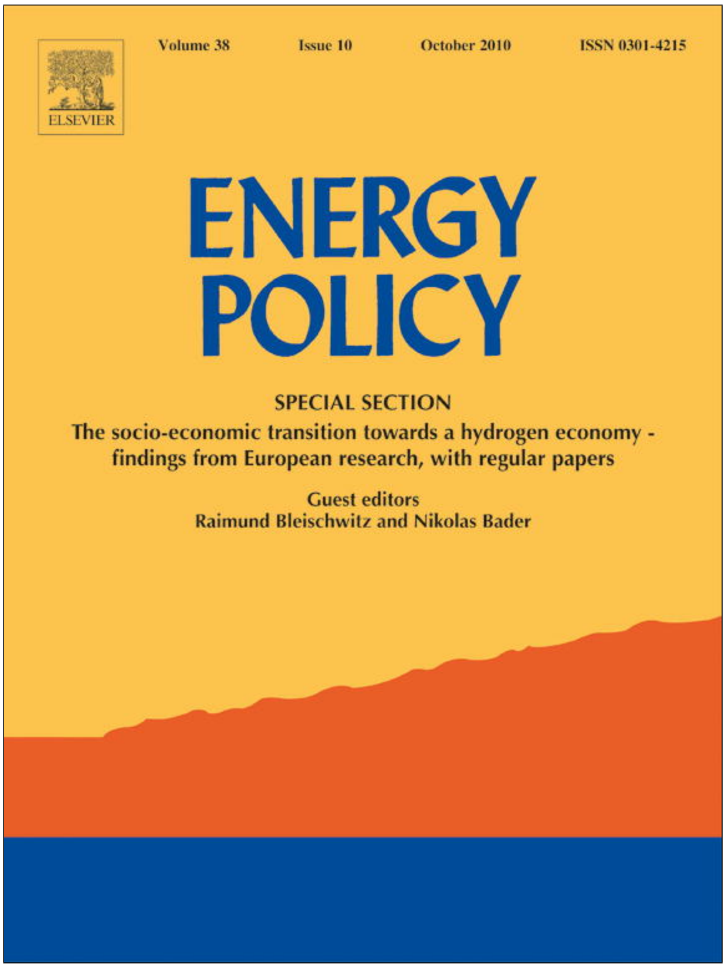
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Comparison of fixed versus variable biofuels incentives

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ABSTRACT

We evaluated several variants of a variable biofuel subsidy and compared them with the fixed subsidy and Renewable Fuel Standard using two different modeling approaches. First we used a partial equilibrium model encompassing crude oil, gasoline, ethanol, corn, and ethanol by-products. Second, we used a stochastic simulation model of a prototypical ethanol plant. From the partial equilibrium analysis, it appears the variable subsidy provides a safety net for ethanol producers when oil prices are low; yet, it does not put undue pressure on corn prices when oil prices are high. At high oil prices, the level of ethanol production is driven by market forces. From the plant level stochastic analysis, essentially the same conclusions are reached. As with the fixed subsidy, the variable subsidy can increase the net present value (NPV) sufficiently to encourage investment, but with lower risk for the producer, lower probability of a loss from the investment, and often lower expected cost to government. Finally, in the US, the ethanol industry is up against a blending limit called the blend wall. If the blending wall remains in place and no way around it is found, it does not matter much what other policy options are used.

1. Introduction

The United States has used and continues to use a variety of incentives to promote development and operation of the ethanol industry. Since the Energy Policy Act of 1978, ethanol has received a tax credit of one sort or another (Tyner, 2008). Today the main incentives are the volumetric ethanol excise tax credit (VEETC) of 11.9 cents/l of ethanol blended, the Renewable Fuel Standard (RFS) (US Congress, 2007), and a small producer tax incentive. There is a tariff on imported ethanol of 14.3 cents/l plus 2.5% of the value of the import. At today's prices, the total import tariff is about 15.6 cents/l (Taheripour and Tyner, 2008). The imported ethanol is eligible for the 11.9 cent blender credit, so the net tariff is 3.7 cents/l. However, there is an exception to the tariffs. Under the Caribbean Basin Initiative and other laws, ethanol produced or processed in certain Caribbean and Central American regions can come into the US duty- and tariff-free (except for the 2.5% ad valorem duty). The exception is limited to 7% of US ethanol consumption. This paper focuses on the subsidy and RFS.

The RFS is a mandate requiring blending of an amount specified each year of each type of biofuel according to feedstock and production processes. The timing and quantities of the RFS are illustrated in Fig. 1. Corn ethanol is in the category called conventional biofuels and reaches a plateau of 56.8 billion liters per year in 2015. It is important to note that the conventional biofuels permits corn ethanol but it does not mandate it, as other biofuel types also could fill the convention portion. Current national capacity of corn based ethanol including shut down plants is about 47.3 billion liters with another 7.6 billion under construction (Renewable Fuel Association), so we are near the 56.8 billion liter plateau for the RFS. Economically, the RFS functions somewhat like a hidden variable incentive in that the cost of the incentive is higher at low gasoline prices than at high gasoline prices. However, it differs from variable subsidies in terms of who pays the cost. The basic objective of this paper is to provide an economic analysis of the fixed subsidy, variable subsidy, and Renewable Fuel Standard.

2. Basic economics of the current market and policy options

Fig. 2 displays the basic economics of the fixed subsidy and a non-binding RFS. A non-binding RFS is one that is below the level that is being produced by the market. That has been the case historically. The market has always produced a quantity greater than the RFS, so the RFS has no real effect on market price or quantity. The fixed subsidy just shifts up the market demand curve by the amount of the subsidy (note that the demand for ethanol represents the blender derived demand). In other words, because the blender receives the VEETC credit, s/he is willing to pay up to 11.9 cents more per liter than would be the case without the subsidy. In this case, the RFS is drawn to the left of the intersection of the supply curve and the market demand curve. Thus, the RFS has no impact on either market price or quantity.

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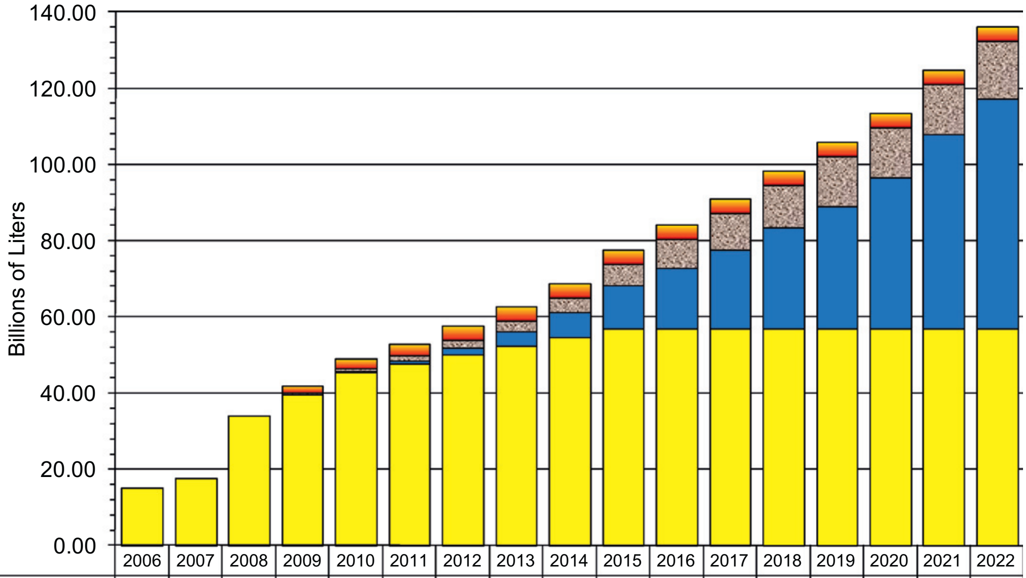

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
🟧 Biomass-based Diesel	0.00	0.00	0.00	1.89	2.46	3.03	3.79	3.79	3.79	3.79	3.79	3.79	3.79	3.79	3.79	3.79	3.79
▨ Non-celulosic Advanced	0.00	0.00	0.00	0.38	0.76	1.14	1.89	2.84	3.79	5.68	7.57	9.46	11.36	13.25	13.25	13.25	15.14
🟦 Celulosic Advanced	0.00	0.00	0.00	0.00	0.38	0.95	1.89	3.79	6.62	11.36	16.09	20.82	26.50	32.18	39.75	51.10	60.57
🟨 Conventional Biofuels	15.14	17.79	34.07	39.75	45.42	47.70	49.97	52.24	54.51	56.78	56.78	56.78	56.78	56.78	56.78	56.78	56.78

Fig. 1. Renewable Fuel Standard.

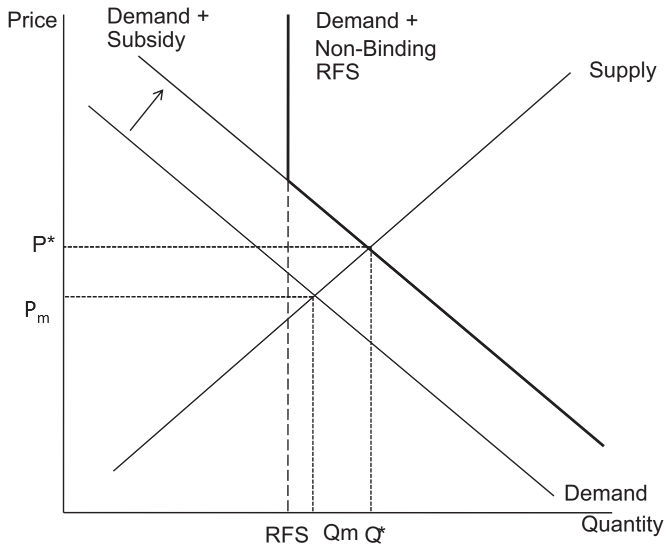

Fig. 2. Ethanol subsidies and non-binding RFS.

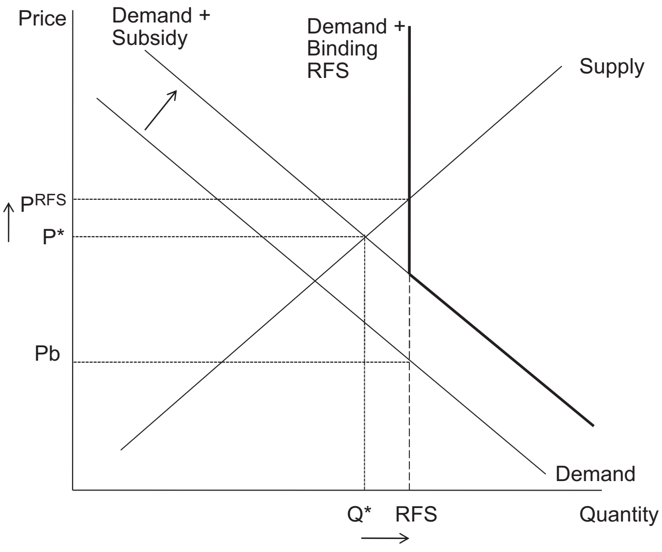

Fig. 3. Ethanol subsidies and binding RFS.

Market price (P^*) and quantity (Q^*) are determined by the intersection of the supply curve and the demand plus subsidy curve. If there were no subsidy, the market price and quantity would be P_m and Q_m. The ethanol producer gets the difference between P^* and P_m of the subsidy with the rest going to the blender. The sharing of the subsidy between the ethanol producer and the blender depends on the supply and demand elasticities (Taheripour and Tyner, 2007).

Fig. 3 shows the case of a binding RFS. For this case, the RFS is to the right of the intersection of the supply curve and the demand plus subsidy curve. The mandated quantity of ethanol is the level of the RFS, and the price is P^{RFS}. Thus, for quantities of ethanol less than the RFS, the demand curve is vertical at the RFS quantity (totally inelastic). The price (P^{RFS}) is given by the intersection of the RFS line and the supply curve. The market price for ethanol and the market quantity are higher than they would be in the absence of the binding RFS. In this case, the ethanol producer would receive P^{RFS} for each unit of ethanol produced at the mandated level of RFS. However, the economic value of ethanol for the user (blender) at the RFS is just P_b, the intersection of the demand with no subsidy and the RFS line. The difference between P^{RFS} and P_b can be considered as a rent for ethanol producers and someone must pay it. It could be covered by a government subsidy or a transfer payment from blenders to ethanol producers through the market for the Renewable Identification Numbers (RINs). Of course, blenders may transfer a portion of their payment for the RINs to other agents of the fuel market such as refineries or gasoline consumers. When there is a government subsidy, the subsidy has no impact on the quantity or P^{RFS}, but it reduces the prices of RINs.

In the case of the non-binding RFS, the subsidy induced higher ethanol production. With the binding RFS, the subsidy has no impact on ethanol production or the price received by ethanol producer (P^{RFS}), but it reduces the price paid by the blenders for ethanol. As noted before, the ethanol demand curve is derived from the gasoline demand and is defined uniquely for each oil price. Each increase in the oil price would induce an outward shift in the demand for ethanol, which eventually (as shown in Fig. 2) would render the RFS non-binding again, and ethanol production would be driven by market supply and demand forces.

2.1. Blend wall

Fig. 4 illustrates the economics of a binding blend wall. We developed this framework to represent the current US ethanol market condition. A blend wall is a physical or technical constraint on the amount of ethanol that can be blended. In the US currently, it is dictated by the 10% blending limit. However, we cannot blend 100% of gasoline, so the effective blend wall is around 9% or less, or somewhere between 42 and 45 billion liters of ethanol (Tyner et al.; Tyner and Taheripour, 2008b). Moving down the demand plus subsidy curve from left to right, the market demand is the demand up to the blend wall. At that point, no more ethanol can be absorbed because of the physical blending limit. E85 potentially could relax the blend wall, but at least near term it is not likely to provide much of an outlet for ethanol, as distribution (fueling stations) and consumption (flex-fuel vehicles) infrastructure is quite limited (Tyner and Viteri, 2010). So at the blend wall, the demand plus subsidy curve becomes vertical, and the market price is the intersection of the blend wall and the supply curve. The market price in Fig. 4 (P^{BW}) is lower than P^* and P^m. In this case the subsidy is shared between the consumer and blender with none going to the ethanol producer. The subsidy has no impact on market quantity because that is set by the physical limit of the blend wall. But in this case, the blend wall forces the price down to the supply curve at the blend wall quantity. Essentially, that is one reason why we observe shut down capacity in the current condition. We are at or near the effective blend wall, and more ethanol is being offered to the market than can be absorbed, so the price falls. There are, of course, other drivers of the shut downs, such as poor management decisions and tight financial markets. Essentially, in the presence of a blending wall ethanol moves from being priced primarily by the crude and gasoline prices to being priced primarily by the corn price. In this case, the price of corn will be the major determinant of ethanol price. In the presence of a blending wall capacity comes in or out based on changes in the price of corn relative to ethanol.

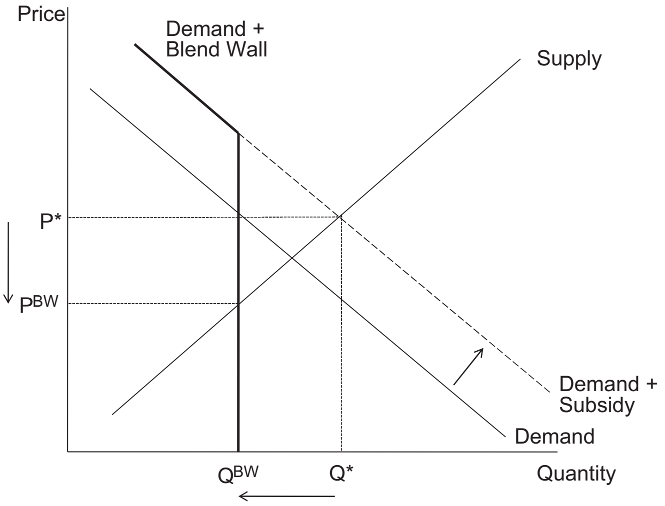

Fig. 4. Impact of the ethanol blending wall.

Currently, the blend wall is the biggest issue facing the ethanol industry. It is important to understand that if the blending wall remains effective, then none of the other policy options effectively matter. The RFS cannot be enforced because the EPA cannot require blenders to blend that which they cannot legally blend. The subsidy, whether fixed or variable, does not matter because it all goes to the consumer and the blender and not to the ethanol producer. Ways around the blend wall include massive investment in E85 distribution and consumption infrastructure and producing butanol or hydrocarbons directly from cellulosic feedstocks (Tyner and Viteri, 2010). In what follows we assume that these options or others are followed such that the RFS and subsidies become the operative policy environment. Hence, in what follows we analyze impacts of other policy options in the absence of the blending wall.

3. Policy analysis

Like a fixed subsidy, a variable subsidy inversely related to oil prices can also reduce the risks of a loss to venture capitalists, but often at a lower cost to government than the fixed variety. Investor Vinod Khosla indicates that such risk reduction, where firms can avoid a negative profit venture, is key from a capital formation perspective (Snell, 2007). In our prior work, we have evaluated variable incentives compared with the fixed VEETC and RFS (Quear and Tyner, 2006; Tyner and Taheripour, 2008a, 2008d; Tyner, 2007a, 2007b, 2008; Tyner and Quear, 2006). However, we have not performed a detailed evaluation of different variants of the variable incentive. In this paper we define several variants of a variable biofuel subsidy and compare them with the fixed subsidy and RFF using a partial equilibrium model which links the US energy and agricultural markets (Tyner and Taheripour, 2008c, 2008d).

In addition, we develop a stochastic cost–benefit analysis framework to compare impacts of the variable and fixed subsidies on the profitability and government support of a representative ethanol producer under uncertain conditions. The use of stochastic models to analyze the feasibility of a project or investment in a cost–benefit framework is well documented (Campbell and Brown, 2003). Furthermore, stochastic models have been used to study the impacts of ethanol support policies on prices and short-run shut down conditions for firms facing fixed subsidies (McPhail and Babcock, 2008) as well as variable subsidies based on spreads between marginal ethanol production costs and gasoline prices (Bean, 2008). However, our stochastic model is believed to represent the first effort to analyze the impact of a variable ethanol subsidy on firm level investment decisions related to profitability and risk. The model simulates uncertainty in crude oil, gasoline, and corn prices, and calculates the plant investment net present value distribution under both fixed and variable type incentives. The stochastic model is designed to reflect the inherent market uncertainty from the perspective of a representative ethanol plant.

Since the existing fixed subsidy expires in 2010, Congress will be compelled to act on it in one way or another in 2010. Hence it is important to provide additional information on possible options in choosing future directions. The rest of the paper is divided into the following sections:

(1) An analysis of different variable and fixed subsidy options and the RFS.
(2) An analysis of the same fixed and variable subsidy options using a stochastic ethanol plant financial analysis model.
(3) Summary and conclusions of the research.

3.1. *Evaluation of policy options with a partial equilibrium model*

To perform our policy analyses we first update our partial equilibrium model to expand the set of options evaluated. Appendix A contains a summary of the model and an explanation of how it works. The two main changes made in the model for this analysis are as follows:

(1) In the previous work we have included a 5% gasoline demand shock to account for growth in income and population over time. This shock is independent of the standard linkage between the price of gasoline and quantity demanded. For this paper, we have eliminated the demand shock for two main reasons: (1) Because of the recession, incomes have fallen, and demand has fallen due to that income effect and (2)the *Energy Independence and Security Act of 2007* (EISA) (US Congress, 2007) contains a requirement for a substantial increase in automobile fuel economy by 2020. Thus, for any given population and income, gasoline demand will be lower because of the increase in the Corporate Average Fuel Economy (CAFE) standard.
(2) We changed the linkage between the cost of producing corn and the price of crude oil. There is, of course, still a link between the crude oil price and the corn cost of production. However, in 2009, the link between the price of crude oil and the price of natural gas has been disrupted. There have been substantial new discoveries of natural gas in the U.S., which have caused the price of natural gas to plummet. The price of natural gas today is no more than 1/3 of what it was a year ago. Natural gas is the main ingredient in producing nitrogen fertilizer—a main cost component for corn production. So while we retained the link between the corn production cost and the price of crude oil, we cut the oil price coefficient in half for this analysis.

The variable subsidy, as we have defined it in the past, has two components: the trigger price of oil below which the subsidy takes effect and the rate of increase in the subsidy as the oil price drops below the trigger price. For example, if the subsidy is triggered when the crude oil price drops below $80 and increases at a rate of 0.50 cents/l per dollar of change in the crude price, the applied subsidy at various oil prices would be as shown in Table 1. The variable subsidy could be operated on either a monthly or quarterly basis. For example, if a quarterly basis were used and the crude oil price were $50 in quarter one, then the subsidy on ethanol produced in quarter two would be $0.15/l. of ethanol according to Table 1. The same approach would apply while assuming a monthly basis.

In the analysis that follows, we display results for the following options:

- Fixed subsidy of 11.9 cents/l.
- Fixed subsidy of 6.6 cents/l.
- Variable subsidy starting at $70, $80, and $90 of crude oil price per barrel
- Variable subsidy with a rate of increase of 0.40, 0.46, and 0.53 cents/l per dollar drop in the crude oil price (run at each oil price starting point)
- RFS of 56.8 billion liters
- No subsidy or RFS

Table 1
Illustration of the variable subsidy starting at $80 and changing at 0.50 cents/l/$.

Crude oil price/bbl	Subsidy (cent/l)
$80 or greater	0
$70	5
$60	10
$50	15
$40	20

In these cases we assume that there is no blending wall. In this analysis ethanol producers will receive a share of the subsidy, whether fixed or variable, depending on the market conditions and elasticities of the demands for and supplies of gasoline, ethanol, and corn. Furthermore, we assume that the RFS is fully enforced.

Results from this model are numerous. First, Fig. 5 compares ethanol production under alternative policies. In particular, this figure compares four policies: the fixed 11.9 cent subsidy, a variable subsidy starting at $90 crude oil with a 0.46 cents/l rate of increase, no subsidy, and the RFS. Several important points emerge from this first set of results:

- Crude oil price must be at least $60 for there to be any ethanol production if there is no subsidy or RFS. It is important to note that the corn price is an endogenous variable in our model and goes down with the crude oil price. The prices of corn under all policy options and for all crude oil prices are shown in Fig. 6.
- At low oil prices, the variable subsidy option results in greater ethanol production than the fixed option.
- At oil prices below $80, the RFS results in greater ethanol production than either the fixed or variable subsidy.
- At oil prices greater than $80, the fixed subsidy yields greater ethanol production than any of the other options. As we will see below, it also induces higher corn prices than the other options.
- At oil prices above $80, the variable subsidy and no subsidy options produce the same results because the variable subsidy ends at $90.
- At oil prices of $120 and higher, the no subsidy, variable subsidy, and RFS options all yield the same results. There is no subsidy at these oil prices for the variable subsidy, and the RFS is no longer binding, meaning the market is producing more than the mandated 56.8 billion liters.

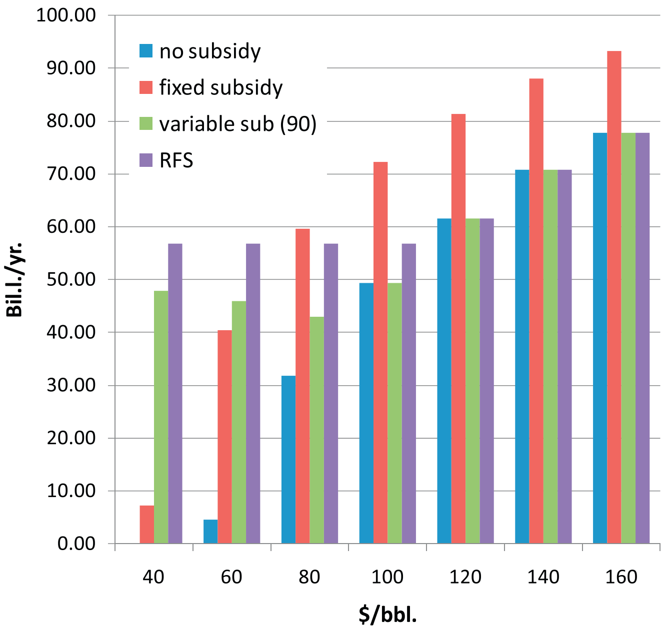

Fig. 5. Base comparison of ethanol production under subsidy options and RFS.

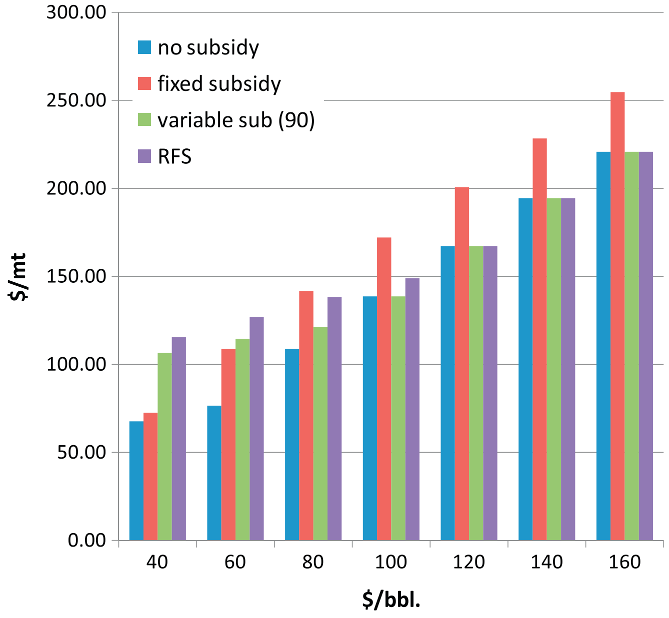

Fig. 6. Base comparison of corn price under subsidy options and RFS.

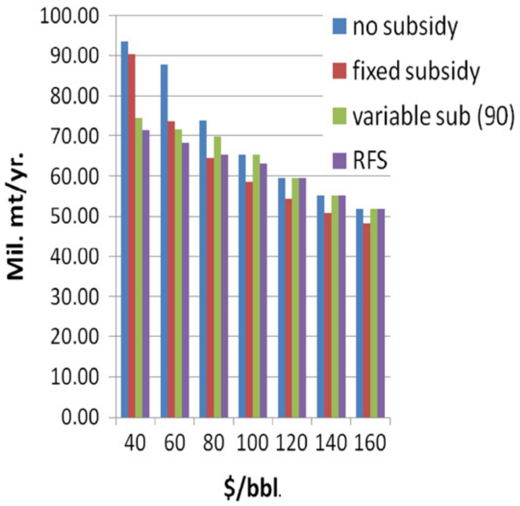

Fig. 7. Corn exports under alternative policy options.

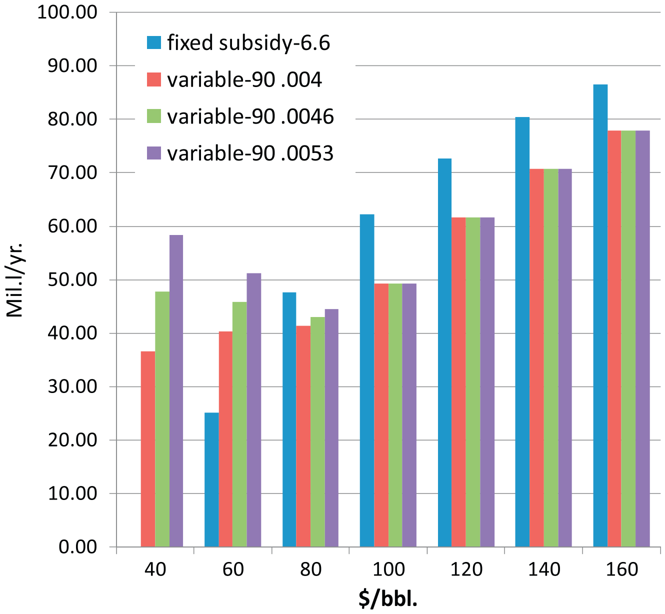

Fig. 8. Ethanol production under different fixed and variable subsidy options.

Fig. 6 shows the corn price results for the same policy alternatives mentioned above. The main conclusions with respect to corn prices are as follows:

- Corn price is higher under the variable subsidy than the fixed subsidy for crude prices of $60 and below.
- Corn price goes to $255/mt at $160 crude oil under the fixed subsidy, about $34/mt higher than the other options.
- Before the crude oil price of $100 per barrel, where the RFS is binding and the derived demand of ethanol industry for corn is fixed, the corn price follows an increasing trend with the crude oil price, due partly to the fact that the corn production costs are increasing with the crude oil price. Below the RFS binding oil price, any reduction in corn price would lead to higher quantity demanded of corn for other uses which tends to support the corn price and prevents a large reduction in corn price.

Fig. 7 shows the results of the same simulations for corn exports. The main conclusions regarding corn exports are as follows:

- Corn exports are higher at low oil prices for the fixed and no subsidy cases compared to the variable subsidy and RFS cases. That stands to reason because the variable subsidy and RFS are a more potent incentive for ethanol production at low oil prices than either the no subsidy or fixed subsidy cases. In particular, there is no ethanol production at low oil prices without the subsidy, so more corn gets allocated to exports.
- At high oil prices, the RFS and variable subsidy lead to a lower drop in exports than the fixed subsidy case. At high oil prices, the RFS is no longer binding, and the variable subsidy is the same as no subsidy since the variable subsidy ends at $90 crude oil in this case.
- At $80 crude oil, the variable subsidy yields higher exports than either the RFS or fixed subsidy, which are about the same.

Next, we compare the $90 variable subsidy with three different slopes against the fixed subsidy at 6.6 cents. The other cases are dropped from this graph for clarity of presentation. Fig. 8 shows the results for ethanol production, and Fig. 9 for corn price. Table 2 gives the complete ethanol and corn price results for all three starting points and rates of change. For ethanol production and corn price, the variable subsidy yields higher levels at oil prices of $40 and $60, and the 6.6 cent fixed subsidy is about the same as the variable subsidy at $80 crude oil. For crude oil of $100 or higher, the fixed subsidy yields both higher ethanol production and corn price. For the variable subsidy beginning at $90, the higher slope of 0.53 cents/l per dollar actually results in higher ethanol production at $40 crude oil than at $100 crude because the subsidy grows to be quite large at low oil prices.

The 0.40 and 0.46 cents/l per dollar rates of change produce more reasonable results with the $90 starting point in that the safety net is provided, but not so much as to change significantly the profitability as oil price increases. On the other hand, with the $70 starting point, the higher slope is needed to stimulate significant ethanol production at low oil prices. The $80 case, as would be expected, is in between these two.

Based on these results, it appears that the variable subsidy can provide a safety net for periods of low oil prices, while not providing a stimulative effect when oil prices are higher. We now turn to the analysis of these options performed using an ethanol plant level model.

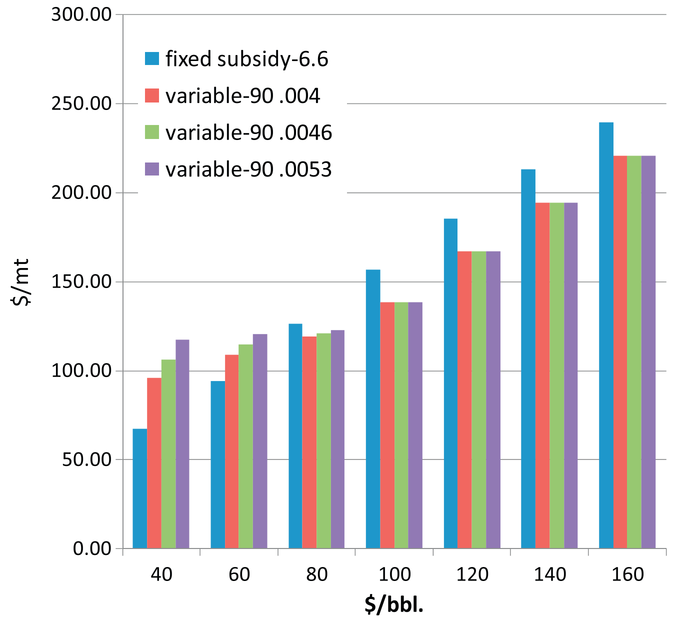

Fig. 9. Corn price under different fixed and variable subsidy options.

3.2. *Ethanol plant simulation model based analysis*

The ethanol plant based simulation analysis is performed using a modified plant level model (Dale and Tyner, 2006a, 2006b; Perkis et al., 2008). The model was previously used to evaluate new technology options in corn ethanol production. It was modified for purposes of this analysis to permit stochastic analysis of the ethanol plant profitability. While a number of changes were made, we will summarize briefly here the main changes that are important to this paper:

- Crude oil price is uncertain. In a base case scenario, future prices are forecasted using a mean-reverting regression for commodities as described in Blanco and Soronow (2001). Regression parameters are estimated based on crude oil prices in the time period 1968–2009 after being adjusted for inflation by the consumer price index (CPI). A random component is defined using the residuals from the regression estimate. Starting with oil prices in 2009, the regression forecasts prices for all remaining years of a 25 year production facility. Operations are assumed to begin in 2011. The distribution of all forecasted years can be seen in Fig. 10.
- An alternate oil price forecast is developed based on predicted prices in the Energy Information Administration's (EIA) 2009 Annual Energy Outlook. Starting with the mean reverting regression from the base case, the long term mean and the random deviation are scaled up equally so that volatility (the standard deviation of the random component normalized by the oil price mean) remains the same. The amount of scaling is determined so as to minimize the sum of squared differences between the new mean-reverting forecasted prices and the 2009 Energy Outlook price forecasts (Fig. 11).

Table 2
Simulation results for a range of subsidy start points and rates of change.

Crude oil price $/bbl	40	60	80	100	120	140	160
Ethanol production (Bil. l/yr)							
Fixed subsidy (6.6 cents/l)	0.0	25.1	47.6	62.3	72.7	80.5	86.5
Variable: 0.40 cents/$1 below $90/l	36.7	40.4	41.4	49.3	61.6	70.7	77.8
Variable: 0.46 cents/$1 below $90/l	47.8	45.9	43.0	49.3	61.6	70.7	77.8
Variable: 0.53 cents/$1 below $90/l	58.3	51.2	44.5	49.3	61.6	70.7	77.8
Ethanol production (Bil. l/yr.)							
Fixed subsidy (6.6 cents/l)	0.0	25.1	47.6	62.3	72.7	80.5	86.5
Variable: 0.40 cents/$1 below $80/l	22.5	29.0	31.8	49.3	61.6	70.7	77.8
Variable: 0.46 cents/$1 below $80/l	32.0	32.9	31.8	49.3	61.6	70.7	77.8
Variable: 0.53 cents/$1 below $80/l	41.2	36.7	31.8	49.3	61.6	70.7	77.8
Ethanol production (Bil. l/yr)							
Fixed subsidy (6.6 cents/l)	0.0	25.1	47.6	62.3	72.7	80.5	86.5
Variable: 0.40 cents/$1 below $70/l	7.2	17.1	31.8	49.3	61.6	70.7	77.8
Variable: 0.46 cents/$1 below $70/l	15.0	19.1	31.8	49.3	61.6	70.7	77.8
Variable: 0.53 cents/$1 below $70/l	22.5	21.1	31.8	49.3	61.6	70.7	77.8
Corn price ($/mt)							
Fixed subsidy (6.6 cents/l)	67.6	94.1	126.6	156.9	185.6	213.0	239.4
Variable: 0.40 cents/$1 below $90/l	96.1	108.9	119.3	138.6	167.0	194.3	220.7
Variable: 0.46 cents/$1 below $90/l	106.5	114.7	121.1	138.6	167.0	194.3	220.7
Variable: 0.53 cents/$1 below $90/l	117.2	120.6	122.9	138.6	167.0	194.3	220.7
Corn price ($/mt)							
Fixed subsidy (6.6 cents/l)	67.6	94.1	126.6	156.9	185.6	213.0	239.4
Variable: 0.40 cents/$1 below $80/l	84.0	97.7	108.6	138.6	167.0	194.3	220.7
Variable: 0.46 cents/$1 below $80/l	92.0	101.4	108.6	138.6	167.0	194.3	220.7
Variable: 0.53 cents/$1 below $80/l	100.2	105.1	108.6	138.6	167.0	194.3	220.7
Corn price ($/mt)							
Fixed subsidy (6.6 cents/l)	67.6	94.1	126.6	156.9	185.6	213.0	239.4
Variable: 0.40 cents/$1 below $70/l	72.6	87.0	108.6	138.6	167.0	194.3	220.7
Variable: 0.46 cents/$1 below $70/l	78.2	88.7	108.6	138.6	167.0	194.3	220.7
Variable: 0.53 cents/$1 below $70/l	100.2	105.1	108.6	138.6	167.0	194.3	220.7

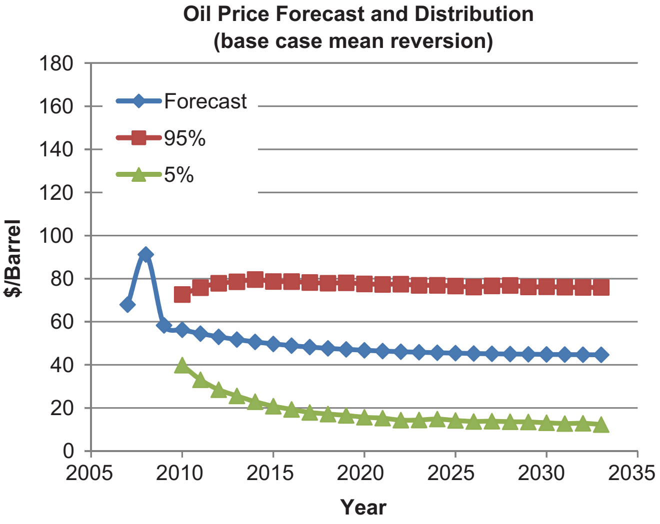

Fig. 10. 2010–2033 oil price forecast, base case.

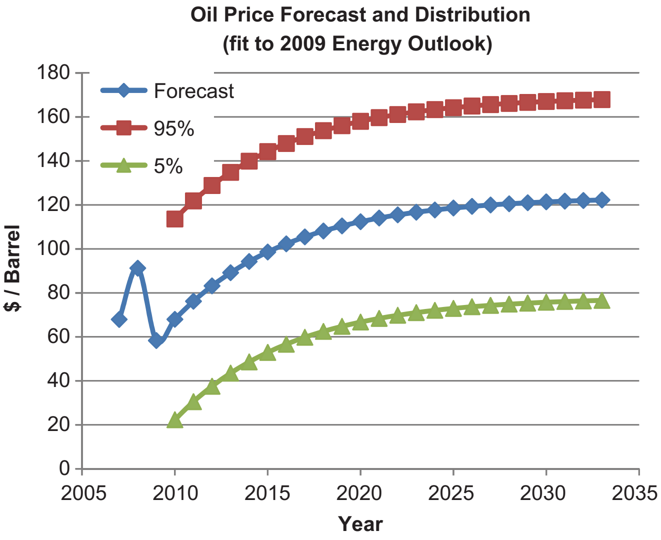

Fig. 11. 2010–2033 oil price forecast, alternate case.

- We estimated the historical relationship between crude oil and gasoline using monthly data for January 2007–December 2009. During this period, prices are highly correlated with a coefficient of 0.95.
- We also estimated the link between crude oil and corn over this same period, finding a strong correlation of 0.80. In this case the regression residual introduced more corn price variability.
- We used the historical empirically estimated price link between corn and DDGS.
- For this paper, we assumed volumetric pricing of ethanol. That is, we assumed the ethanol price equaled the gasoline price plus any subsidy in effect.
- Even though the model allows the subsidy pass-through percentage to producers to be stochastic, we used 100% pass through in this analysis to have a good basis for comparison of alternatives.

The policy options examined in this part of the research were essentially the same as in the previous section, but we focused more on the rate of change of 0.46 cents/l per dollar of crude oil price difference, as this rate appeared to work well in the previous section's results. One additional approach we added in this section is letting the starting point for the variable subsidy be held constant in nominal terms or be adjusted each year by the rate of inflation. For example, in the nominal case, assuming a $90 starting point for the variable subsidy, the nominal level did not change over the assumed 25 year plant life (two years of construction and 23 of operation). The real case increased the crude trigger price each year by the rate of inflation.

The simulations were performed with @Risk software (@Risk, 2008). @Risk is an add-in for the Excel spreadsheet that permits Monte Carlo simulation. That is, it calculates the inherent uncertainty in all the output values given the uncertainty reflected (and described above) in input variables. The spreadsheet is recalculated many times (we used 10,000 iterations for each simulation). @Risk calculates the mean, standard deviation, and other parameters of the output distributions.

The results for the nominal subsidy starting point are provided in Table 3. The first column contains the parameters of the system being simulated, with the variable subsidy systems denoting in parentheses both the trigger price and the rate of change ($/barrel crude, $/l ethanol per $/barrel crude). The column labeled "value" contains the non-stochastic results for the net present value (NPV) after 25 years of construction and operation. The columns labeled mean and SD are the average NPV and the standard deviation of NPV for each policy option. The column labeled SD/mean is the coefficient of variation (CV), which is a standard measure of riskiness of the investment. The column labeled "% < 0" is the probability that the investment will result in a loss. The two columns under subsidy NPV are the average and standard deviation of government subsidy costs. Finally, the two columns under Govt NPV Revenue are the NPV average and standard deviation of the government's net subsidy cost after allowing for government revenue from taxes paid over the plant lifetime. The difference between the subsidy NPV and Govt. Rev. NPV is the NPV of taxes paid. For example, for the fixed subsidy case, the NPV subsidy cost is $316 million, but the net cost to government is $75 million, so $241 million is the NPV of taxes paid by the firm over the 25 years.

For the base case oil price scenario, it is instructive to compare the fixed subsidy (11.9 cents) with government's breakeven variable subsidy ($90.6 trigger price). Note that the fixed subsidy mean or expected NPVs are similar to the values with no risk analysis, but the variable subsidy cases are higher. That is because it is only with the stochastic analysis that one can get a true indication of the functioning of the variable subsidy. Without the price varying each year, only the "expected" subsidy gets calculated. Technically, the large difference occurs because the variable subsidy is a type of non-linear transformation that makes the deterministic spreadsheet case give very different results from the Monte Carlo simulations. The expected plant NPVs are $91 million for both the fixed and variable cases. The coefficients of variation (CVs) are 1.02 and 0.43 for the fixed and variable cases, respectively. A higher CV means higher risk, so the variable subsidy case is less risky for the firm. The probability of a loss is 16.8% for the fixed subsidy case and 0.6% for the variable subsidy case, another indicator of risk. Thus, this variable subsidy has the same expected government cost as a fixed subsidy but with a much lower risk to firms of taking a loss. As the trigger price is decreased for the variable subsidy, expected government costs decrease in comparison to the fixed subsidy, even while the risk of a loss is still less than the fixed subsidy case. In fact, all **shaded** rows represent policy options which both decrease the probability of a loss to the firm and lower the expected expense to taxpayers when compared to the fixed subsidy outcomes. It is important to note, of course, that the risk does not disappear—it is

Table 3
Results for the fixed trigger price (nominal) variable subsidy case.

Volume priced ethanol	Firm NPV					Subsidy NPV		Govt NPV revenue	
NPV, Financial w/tax	**Value**	Mean	SD	SD/Mean	% < 0	Mean	SD	Mean	SD
Annual outlook adjusted crude prices									
Fixed subsidy	536	548	245	0.45	0.4	316	0	−75	82
Var. subsidy (140,0.0046)	475	575	132	0.23	0.0	360	258	−103	240
Var. subsidy (133.1,0. 0046)[a]	**447**	**548**	**142**	**0.26**	**0.0**	**317**	**240**	**−75**	**229**
Var. subsidy (130,0. 0046)	**436**	**536**	**143**	**0.27**	**0.0**	**297**	**231**	**−63**	**221**
Var. subsidy (120,0. 0046)	**404**	**501**	**154**	**0.31**	**0.0**	**240**	**205**	**−26**	**204**
Var. subsidy (110,0. 0046)	**378**	**471**	**168**	**0.36**	**0.0**	**190**	**180**	**7**	**187**
Var. subsidy (100,0. 0046)	**359**	**445**	**180**	**0.40**	**0.0**	**147**	**152**	**34**	**168**
Var. subsidy (90,0. 0046)	**347**	**423**	**188**	**0.44**	**0.0**	**112**	**127**	**57**	**152**
Var. subsidy (80,0. 0046)	**343**	**405**	**202**	**0.50**	**0.1**	**82**	**105**	**76**	**138**
Var. subsidy (74.0,0. 0046)[b]	**343**	**395**	**205**	**0.52**	**0.4**	**66**	**90**	**87**	**128**
Var. subsidy (70,0. 0046)	343	390	213	0.55	0.8	58	82	92	124
No subsidy	343	354	241	0.68	6.5	0	0	129	81
Base case crude prices									
Fixed subsidy	89	91	93	1.02	16.8	316	0	−228	31
Var. subsidy (100,0. 0046)	137	152	38	0.25	0.0	416	164	−292	136
Var. subsidy (90.6,0. 0046)[a]	**68**	**91**	**39**	**0.43**	**0.6**	**316**	**151**	**−228**	**127**
Var. subsidy (90,0. 0046)	**63**	**87**	**38**	**0.44**	**0.8**	**310**	**150**	**−224**	**126**
Var. subsidy (81.7,0. 0046)[b]	**5**	**39**	**41**	**1.05**	**16.8**	**230**	**135**	**−172**	**116**
Var. subsidy (80,0. 0046)	−6	30	42	1.40	23.6	216	133	−163	115
No subsidy	−104	−102	95	−0.93	85.8	0	0	−23	32

[a] Breakeven point for expected government costs.
[b] Breakeven point for probability of a loss.

transferred from the private to the public sector in higher variability of subsidy payments. Since private sector risk reduction is one of the major objectives of such policies, this transfer is to be expected.

It is also instructive to determine the impact of prices not matching expectations. For instance, suppose policy makers assume that prices will revert to their long term trend and based on the bottom half of Table 3, they establish a variable subsidy with a trigger price of $90.6 in order to minimize risk to firms at the same cost to government as a fixed subsidy. Then suppose that prices more closely match the Annual Energy Outlook projections. Based on the top half of Table 3, a variable subsidy with a trigger price of $90 would both reduce the risk of a loss (0.0% vs. 0.4%) and improve government revenues ($57 million income vs. a $75 million loss) when compared to the fixed subsidy. It is encouraging that policies established given long term trends in oil prices would continue to provide benefits if prices trend upward as expected by forecasts. Furthermore, an upward trend in prices would provide greater flexibility in designing a variable subsidy as the desired benefits can be realized over a larger range of trigger prices.

Table 4 provides similar results for the inflation adjusted trigger price for the variable subsidy. For the high oil price forecast, inflation adjusted crude trigger prices of $60–$100 yield results with less likelihood of a loss to firms, while also being less expensive for government. Similarly, if oil prices followed the base case, a trigger price of $65 would still provide both benefits of lower risk and lower government cost. It is logical that the subsidy's crude trigger price for the inflation adjusted (real) case would be lower than the fixed trigger price (nominal) case. In a sense, it is more flexible in that it adjusts higher with increases in inflation. Fig. 12 illustrates the win–win zone for both the real and nominal trigger prices. The win–win zone is defined as the region in which firm risk goes down and government cost goes down.

Finally, it is important to note that while the breakeven case for risk will prevent a loss to firms with the same probability as the fixed subsidy case, their return on investment will likely be lower. However, such returns would still be greater than if there were no subsidy at all. In other words, the government's role is to encourage ethanol production by reducing private sector risk of loss at the lowest cost possible to government.

3.3. *Implementation issues*

As described briefly above, the variable subsidy would be implemented either on a quarterly or monthly basis. It would make use of a publically available and reported crude oil price so that everyone in the market would be able to calculate or estimate the subsidy level for the following period. There would be a lag of one period, so the Q2 subsidy would be calculated from Q1 oil prices. Once fixed for the quarter, the subsidy would be implemented just as under the current system. That is, blenders would take a deduction from their excise tax bill for the ethanol blended during the quarter using the subsidy value for that quarter. So in that sense, there would be no difference in implementation between the current fixed VEETC and variable VEETC except that the level would change each period.

In periods of high volatility, it is possible that just before and after the subsidy level changed, firms would attempt to move up or back transactions to take advantage of higher subsidies in one period or the other. It is not expected that this time arbitrage would pose significant problems, but it might merit further review.

4. Summary and conclusions

If the blending wall remains in place, it does not matter much for what other policy options are used. The RFS would have to be waived down to the blend wall level. In the presence of the blending wall the subsidy (VEETC), whether fixed or variable, goes to the consumers, blenders, and refiners and not to the ethanol producer. The policy analysis we did assumes the blend wall problem is solved.

We have evaluated several variants of a variable subsidy and compared them with the fixed subsidy and RFS. In general, it appears the variable subsidy provides a safety net for ethanol producers and corn growers when oil prices are low; yet, it does

Table 4
Results for the inflation adjusted trigger price (real) variable subsidy case.

Volume priced ethanol	Firm NPV					Subsidy NPV		Govt NPV revenue	
NPV, Financial w/tax	Value	Mean	SD	SD/Mean	$\% < 0$	Mean	SD	Mean	SD
Annual outlook adjusted crude prices									
Fixed subsidy	536	548	245	0.45	0.4	316	0	−75	82
Var. subsidy (110,0. 0046)	435	583	115	0.20	0.0	374	275	−112	253
Var. subsidy (103.6,0. 0046)[a]	**403**	**548**	**126**	**0.23**	**0.0**	**316**	**250**	**−75**	**236**
Var. subsidy (100,0. 0046)	**389**	**529**	**133**	**0.25**	**0.0**	**286**	**236**	**−55**	**226**
Var. subsidy (90,0. 0046)	**360**	**487**	**154**	**0.32**	**0.0**	**216**	**200**	**−10**	**203**
Var. subsidy (80,0. 0046)	**345**	**449**	**170**	**0.38**	**0.0**	**155**	**160**	**29**	**176**
Var. subsidy (70,0. 0046)	**343**	**420**	**187**	**0.45**	**0.0**	**108**	**126**	**60**	**153**
Var. subsidy (60,0. 0046)	**343**	**398**	**201**	**0.51**	**0.1**	**71**	**93**	**83**	**131**
Var. subsidy (55.1,0. 0046)[b]	**343**	**390**	**209**	**0.54**	**0.4**	**58**	**81**	**92**	**124**
Var. subsidy (50,0. 0046)	343	382	218	0.57	1.1	45	67	100	116
No subsidy	343	354	241	0.68	6.5	0	0	129	81
Base case crude prices									
Fixed subsidy	89	91	93	1.02	16.8%	316	0	−228	31
Var. subsidy (70,0. 0046)	107	118	36	0.31	0.1	360	162	−255	134
Var. subsidy (67.1,0. 0046)[a]	**77**	**92**	**37**	**0.40**	**0.5**	**318**	**155**	**−228**	**130**
Var. subsidy (60.2,0. 0046)[b]	**6**	**37**	**40**	**1.08**	**16.8**	**227**	**135**	**−170**	**117**
Var. subsidy (60,0. 0046)	4	35	40	1.14	18.3	225	135	−168	117
No subsidy	−104	−102	95	−0.93	85.8	0	0	−23	32

[a] Breakeven point for expected government costs.
[b] Breakeven point for probability of a loss.

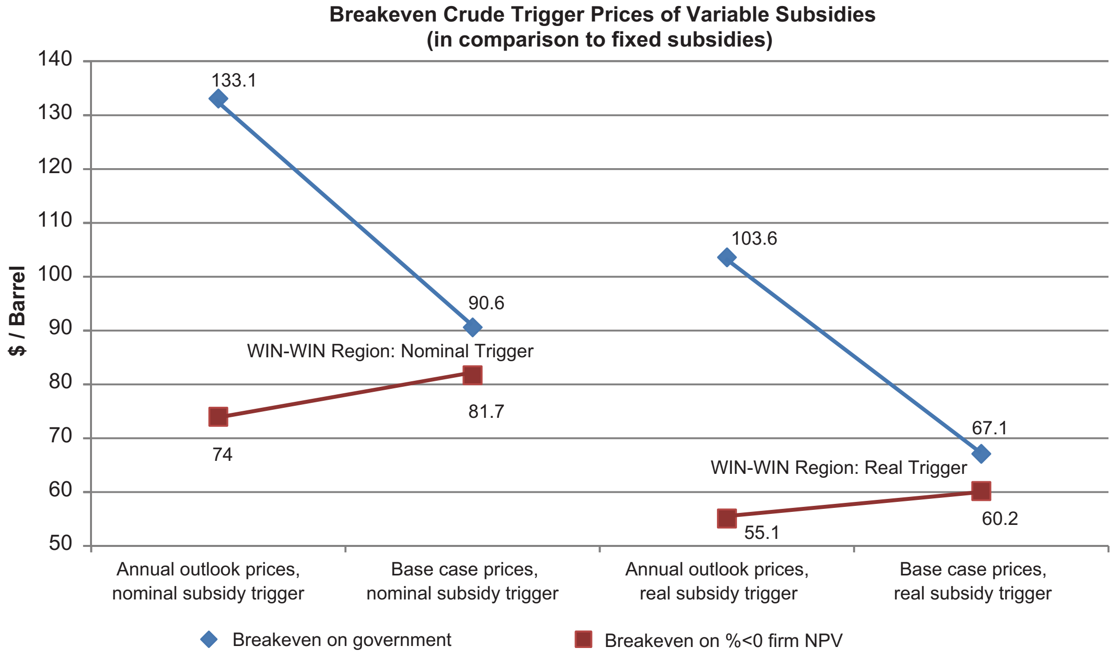

Fig. 12. Win–win cases for oil trigger price.

not put undue pressure on corn prices when oil prices are high. Ethanol production is higher at low oil prices with a variable subsidy, and at high oil prices the level of ethanol production is driven entirely by market forces and not by government interventions. One situation not examined in this paper is the short crop. In that situation the variable subsidy could put more pressure on corn prices than a fixed subsidy, but less than a RFS.

From the plant level stochastic analysis, essentially the same conclusions are reached. The additional information is that the variable subsidy can provide smaller but still significant increases in firm NPV when compared to the fixed subsidy, but with a lower risk for the producer, a lower probability of a loss from the investment, and often at a lower expected cost to government. Both because of the higher level of incentive at lower oil prices and because of the investor risk reduction, we would expect the variable subsidy to increase production capacity at low oil prices.

Acknowledgments

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Table A1
Major model parameters.

Parameter	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 et al. (2006).

[d] This parameter is taken from Parry and Small (2003).

[e] Several papers has 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 if obtained from a time series for the period of 1975–2006. For the work on this paper, the equation was changed to corn=0.64+0.00615∗crude.

Appendix A

A.1. Brief model description

The model contains integrated markets of corn and gasoline (Tyner and Taheripour, 2008c, 2008d). 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, we can define an aggregated Cobb–Douglas production function for the whole market. In the 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, food, and industrial 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 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 of 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 (Tyner et al., 2008).

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 A1. 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). For previous analyses, a 5% demand shock had been assumed, but it is dropped for this analysis as explained in the text. 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.

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