A Real Options Analysis of Ethanol Plant Investment under Uncertainty

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Executive Summary

Ethanol production over the past few years has been both a haven and heartache for investors in corn-based ethanol facilities. Record-high returns in 2006 and 2007 have vanished in the face of precipitous drops in gross margins in 2008. Using a real options approach, we analyze investment and operating decisions of corn-based dry-grind ethanol facilities and identify trigger prices that signal the optimal times in which to change the status of plant operations. Specifically, we identify the levels of gross margins (price of ethanol less price of corn) that trigger firm investment and entry, suspension and reactivation of existing plants, and, finally, exit of plants from the industry.

Margin triggers were estimated for three classes of plants, differentiated by plant size. Entry margin triggers drop from $1.78 to $1.33 per gallon as plants size increases, given economies of size in production. Exit margin triggers are more similar across plant sizes, ranging from $0.17 to $0.13 per gallon. In addition, firms will mothball plants when gross margins drop to around $0.17 per gallon, and later reactivate if margins increase to between $0.66 and $0.79, depending on plant size.

As the variability in gross margins increase, entry and reactivation triggers increase substantially, and decreases the trigger margins to exit and mothball. In fact, relative to the case where margin triggers are estimated using net present value analysis, entry (exit) prices considering real options are, on average, 207% (63%) higher (lower). Such differences highlight the importance of considering price uncertainty for investment decisions in this industry.

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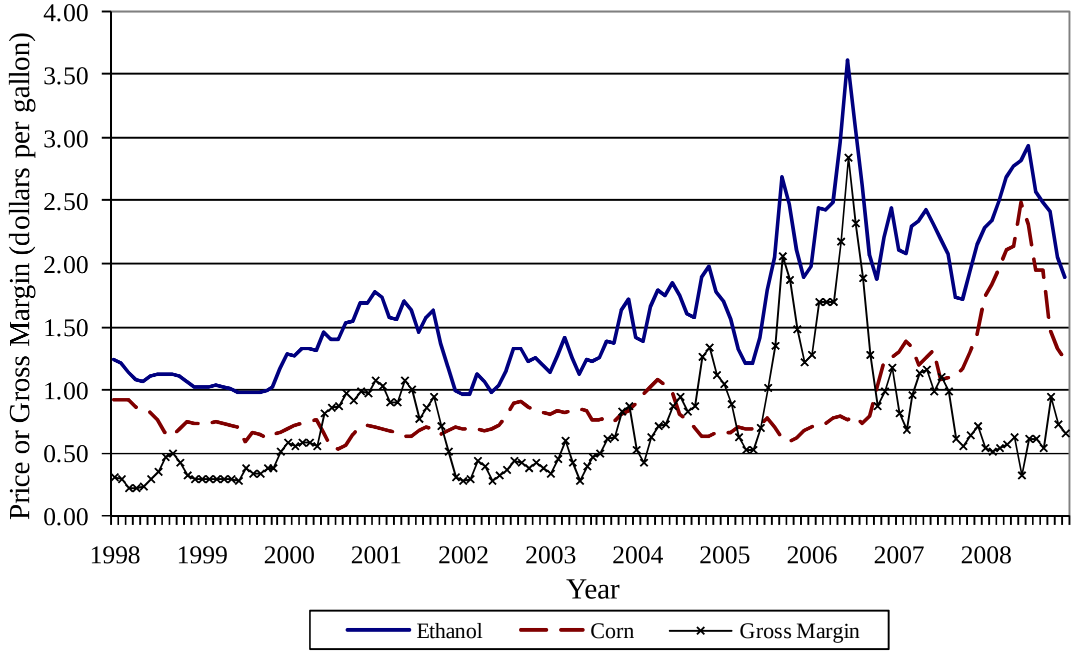
Abstract

A real options approach is used to analyze optimal investment and operating decisions of dry-grind corn ethanol facilities. Estimated margin triggers (ethanol price minus corn price) show that a large plant will enter the industry when margins reach $1.33 per gallon, and will exit when margins drop to $0.17. Prior to exit, however, plants will suspend operations at $0.18 and reactivate if margins rebound to $0.66. Relative to computed net present value triggers, entry (exit) triggers considering real options are, 207% (63%) higher (lower), highlighting the importance of considering price uncertainty for investment decisions in this industry.

Key Words: ethanol processing, investment, net present value, real options

Production and demand for renewable sources of energy are dramatically affecting U.S. commodity markets, and impacting both the levels and volatility of industry returns in alternative energy markets. Such impacts have significant implications for investment and operational decisions of industry decision-makers. Fueled by increased demands for ethanol, due largely to the establishment of the Federal Renewable Fuels Standard (RFS) in 2005 and state bans on the use of methyl tert-butyl ether (MTBE) as an oxygenate additive in gasoline, ethanol gross margins (i.e., the price of ethanol less the price of corn) that were historically in the range of $1 per gallon or less reached record highs in 2006 at nearly $3 (Figure 1), and prompting significant industry expansion.

More recent expansion, however, has been tempered by changing market conditions. Gross operating margins dropped sharply in 2007 and have continued a declining trend in 2008



Data Sources: Datastream and Bloomberg. Assumes ethanol conversion ratio of 2.8 gallons per bushel of corn.

Figure 1. Monthly corn, ethanol, and gross margin prices, 1988-2008.

when increasing ethanol prices earlier in the year failed to keep pace with rising corn prices. The lower operating margins have contributed to the delayed development of some planned corn ethanol facilities (Feinman 2007). With the sharp reductions in crude oil prices later in 2008, both ethanol and corn prices dropped precipitously, with little effect on the already reduced margin levels (Figure 1).

Furthermore, the 2007 Energy Independence and Security Act increased the RFS to 36 billion gallons by 2022, but limited the amount that can come from corn-based ethanol. Similar incentives were adjusted in the 2008 Farm Bill, including reducing the volumetric ethanol excise tax credit (VEETC or blender's credit) \$0.05 to \$0.46. Since this credit provides the incentive for gasoline blenders to bid up the price of ethanol, the credit reduction has implications for firm margins. Gross margins retreated to around \$1 in 2007 and late in 2008 were in the range of \$0.50 to \$0.75 per gallon on a monthly basis.

In addition, commodity and energy prices are exhibiting increased variability. Commodity prices are forecasted to have high upswing potential with increased volatility (Schmit, Verteramo, and Tomek 2008). Investors in ethanol processing need to consider both the levels of costs and prices as well as price volatility when making investment or disinvestment decisions. Whether or not corn-based ethanol will be the preferred renewable energy technology in the future, the development and reformation of this sizable industry remains important across the U.S. agricultural and energy sectors.

We analyze investment and operating decisions of corn-based dry-grind ethanol facilities using net present value (NPV) and real options approaches. NPV analysis is a well established method to investigate investment alternatives. More recently, real option analysis has been used to evaluate agricultural investments (Purvis et al. 1995; Cary and Zilberman 2002; Engel and

Hyde 2003; Isik et al. 2003; Luong and Tauer 2006; Tauer 2006). In essence, the approach of real option analysis applies financial option theory to physical assets, whereby entry and exits by firms are modeled as call and put options. When considering uncertainty, a firm may be reluctant to make an investment because not making that investment preserves the opportunity of making a better investment later. Once the investment is made, however, a firm may be reluctant to exit because it holds the option of keeping the operation going until market conditions improve.

Standard economic theory tells us that firms will not enter an industry unless expected returns will cover both fixed and variable costs, but those already in will not exit until expected returns no longer cover variable costs. The introduction of price variation (and real options) causes this zone of inactivity to widen. The options to exit or enter have value and will not be exercised until the discounted losses or discounted profits exceed the respective value, and therefore altering the price spread without risk considerations.

In addition, firms have operational decisions beyond just getting in or getting out. As prices decrease and the plant begins to incur losses, managers can elect to suspend operations and mothball the plant under reduced maintenance costs. The plant could then be reactivated in the future when prices improve and at a sunk cost less than the original cost of investment. This option may be particularly valid in an immature industry subject to abrupt price fluctuations or, in the case of corn ethanol, in an industry for which the underlying market conditions have shifted dramatically due to market structural changes.

We contribute to and extend the literature on ethanol plant investments and profitability by directly considering the economic values of entering, suspending, reactivating, and exiting the corn-based ethanol industry. Studies of firm investment and operation of ethanol plants have focused largely on break-even analysis, NPV, return on investment, or similar assessments in a deterministic framework, with sensitivity analyses conducted on important costs, technologies, or prices (Eidman 2007; Ellinger 2007; Whims 2002; Gallagher et. al. 2006).

Additional studies of plant investment have incorporated risk and uncertainty via stochastic simulations in the evaluation of firm profitability and returns given various pricing scenarios (Richardson et. al. 2007; Richardson, Lemmer, and Outlaw 2007, Gallagher, Shapouri, and Brubaker 2007), while others have focused on economies of size in production and profitability or costs by firm size (Gallagher, Brubaker, and Shapouri 2005; Gallagher, Shapouri, and Brubaker 2007). In general, however, these approaches take the plant investment as given and evaluate profitability over time given prices and/or price uncertainty. However, none have considered intermediary firm decisions such as temporary suspension of operations.

The application of plant investment decisions considering option values in the ethanol industry has received scant attention. From a similar perspective, Paulson et al. (2008) consider the development of an insurance approach to risk management in the ethanol industry. While the availability of margin insurance would affect returns and investment decisions, the connection to its impact on entry decisions and industry development was not made. Gallagher, Shapouri, and Brubaker (2007) considered option values in their preliminary analyses of the appropriate size of ethanol firms, but argue that plant closure analysis is less important than in the past (prior to 1985) due to the infrequency in which margins dropped below operating costs. While this argument carried merit in the past, large reductions in margins and substantial increases in margin volatility in recent years brings the likelihood that firm need to also consider the possibilities of suspending operation or even exiting the industry.

From this type of analysis, and with firm-specific data, it is possible to identify firm trigger prices that signal the optimal times in which to change the status of plant operations.

From an industry perspective, more effectively capturing these decisions will promote a better understanding and evaluation of optimal industry developments and adjustments. We continue now with a description of the conceptual model and data collected. Next, the empirical results and implications of the research are discussed. We conclude with some summary conclusions and directions for future research

Modeling Exit and Entry Conditions

For the derivations that follow, the ethanol gross margin can be interpreted as the effective price when considering investment and disinvestment decisions. The terms price and gross margin are used interchangeably; e.g., price risk is equivalent to gross margin risk. In considering price risk, we adapt the approach developed by Dixit and Pindyck (1994) to identify ethanol gross margin levels that would encourage entry into or exit from the industry, as well as margin triggers that would induce currently operating firms to suspend operations, and those so suspended to reactivate. To begin, the Dixit and Pindyck (1994) model requires that the investment has an infinite life and is nondepreciating. Presuming that most firms will replace equipment as it becomes depreciated to maintain the capital value, the value of depreciation is included in the firm's operating costs.

Now, suppose one can invest in and operate an ethanol plant that will produce a given level of output and incur constant operating costs, w, for each unit of output. To enter the industry, there is a fixed cost k of investment per unit of output; and for operating plants, there is an exit (or shut-down) cost per unit of output, l, to close it. If some of the original investment can be recovered on exit (i.e., positive liquidation value) those proceeds would reduce other exit costs and can result in an overall negative cost to exit.

Firms also have the options to suspend operations and mothball an active plant, and to reactivate a mothballed plant back to active production. Mothballing requires a sunk cost of $E_m > 0$ per unit of expected output. Assets here remain with the firm and positive costs, such as compensatory costs to displaced laborers, would be incurred. Once a plant is mothballed, a unit maintenance cost of $m > 0$ is required to maintain the existing capital. The plant can be reactivated in the future at an additional sunk cost of r. For the mothballing option to be feasible, we assume $m < w$ and $r < k$.

Denote the threshold price that triggers investment and a new firm to enter as P_h, and the threshold price that triggers an existing plant to exit as P_l. Further, denote the threshold price that triggers an active firm to mothball as P_m, and the threshold price for a mothballed plant to reactivate as P_r. Since the cost of reactivation is less than that of the original investment, we expect that $P_r < P_h$. If we define the Marshallian or NPV trigger prices for entry and exit as $W_h = w + \delta k$ and $W_l = w - \delta l$, respectively (where δ is the discount rate) we can express the relative price relations as: $P_h > P_r > W_h > W_l > P_m > P_l$.

The ethanol gross margin per unit of output (P) is assumed to evolve according to Geometric Brownian motion (GBM) and can be specified as $dP = \mu P dt + \sigma P dz$, where μP is the expected drift rate of P, $\sigma^2 P^2$ is the variance rate of P, and dz follows a Wiener process ($dz = \varepsilon\sqrt{dt}$), with ε being a random draw from a standardized normal distribution. To make the model operational, we require $\delta > \mu$. Normalizing output to unity implies the revenue from the plant is simply P.

Generally, an active firm will choose to mothball before it exits. However, if mothballing costs are sufficiently high or if the liquidation of assets returns sufficiently negative exit costs (l) it may be optimal to exit the industry directly (Dixit and Pindyck 1994). We assume that the expected exit costs (l) are unchanged with the addition of the mothballing option; i.e., the remaining liquidation value of plant assets is the same whether coming from active or mothballed state. In reality, going from an active project to an exit may be more or less costly than when exiting from a mothballed state depending on the particular investment project (Dixit and Pindyck 1994). For ease of exposition, we assume that mothballing is used when price falls to a certain point. Accordingly, there are four switching scenarios: idle to active, active to mothballed, mothballed to active, and mothballed to idle.[1]

The Decision to Enter

Let $V_0(P)$ equal the discounted expected value of an idle project with the option of operating. The idle project is receiving no income but has the prospect of capital gains if activated in the future. If current investors 'sold' the project and invested the proceeds instead, they would earn $\delta V_0(P)$. Equilibrium in the asset market will require:

(1) $\delta V_0(P) = (1/dt)\mathrm{E}_t[dV_0(P)]$,

where $\mathrm{E}_t[\ ]$ is the expectation operator at time t. The left hand side represents the normal return from the value of the investment and the right hand side is the expected capital gain of the idle project. This is a differential equation with stochastic variable P. From Ito's Lemma, we know for a function $V = V(P)$,

(2) $dV = [V_t + \mu P V_0' + (\sigma^2/2)P^2 V_0'']dt + \sigma P V_0' \, dz$,

where $V_t = \partial V/\partial t = 0$ given the infinite time horizon, $V_0' = \partial V/\partial P$, $V_0'' = \partial^2 V/\partial P^2$, and $\mathrm{E}[dz] = 0$. Simplifying (2) and substituting into (1) results in the equilibrium condition:

(3) $\delta V_0 = \mu P V_0' + (\sigma^2/2)P^2 V_0''$ or $(\sigma^2/2)P^2 V_0'' + \mu P V_0' - \delta V_0 = 0$

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[1] We do not consider the option of investing in a project directly to a mothballed state. While in an oligopolistic industry there may be strategic reasons for this to be viable, it is beyond the scope of this article. Generally, it is unlikely that this route would be cheaper than investing in an operational project upfront (Dixit and Pindyck 1994).

The solution to this homogenous, second-order, ordinary differential equation, as shown by Dixit and Pindyck (1994), is:

(4) $V_0 = A_0 P^{-\alpha} + B_0 P^{\beta}$

where A_0 and B_0 are constants to be determined and $-\alpha = [(1-2\mu/\sigma^2)-((1-2\mu/\sigma^2)^2+8\delta/\sigma^2)^{½}]/2 < 0$ and $\beta = [(1-2\mu/\sigma^2)+((1-2\mu/\sigma^2)^2+8\delta/\sigma^2)^{½}]/2 > 1$. Since the project is idle, $V_0(P)$ can be interpreted as the value of the option to enter. As such, $V_0(P)$ should go to zero as P goes to zero. Since $-\alpha < 0$ and $\beta > 1$, this requires $A_0 = 0$, and simplifies (4) to:

(5) $V_0(P) = B_0 P^{\beta}$.

The Decision to Mothball

Now consider a plant that is operating and earning instantaneous net revenue $P – w$. Let $V_1(P)$ denote the value function of the active plant. Equilibrium conditions require:

(6) $\delta V_1 = (P – w) + (1/dt)\mathrm{E}_t[dV_1]$

where the left-hand-side is the normal return if the plant was sold and proceeds invested at δ, and the right-hand-side is the net revenue flow plus the expected capital gain. Analogous to above, the value function for the active plant can be expressed as:

(7) $V_1(P) = P/(\delta - \mu) – w/\delta + A_1 P^{-\alpha} + B_1 P^{\beta}$

where A_1 and B_1 are constants to be determined, $P/(\delta - \mu) – w/\delta$ is the present value of the net revenue, and $A_1 P^{-\alpha} + B_1 P^{\beta}$ is the value of the option to mothball the plant (Dixit and Pindyck 1994). As the price P goes to infinity, the value of the mothballing option goes to zero implying that $B_1 = 0$.[2] Thus, (7) simplifies to:

(8) $V_1(P) = P/(\delta - \mu) – w/\delta + A_1 P^{-\alpha}$.

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[2] In the two-state entry-exit model, the analytics to this point are identical, except that the value of the option to mothball would be replaced with the value of the option to exit.

The Decision to Reactivate or Exit

Now consider a plant that is mothballed and incurring unit maintenance costs of m. Let $V_m(P)$ denote the value function of the mothballed plant with the option of reactivating or exiting. Equilibrium in the asset market requires:

(9) $\delta V_m = (1/dt)\mathrm{E}_t[dV_m] - m,$

where the left-hand-side is the normal return if the firm sold the mothballed plant and invested it at δ, and the right-hand-side is the expected capital gain of the mothballed plant less ongoing maintenance costs. The resulting value function can be expressed as:

(10) $V_m(P) = A_m P^{-\alpha} + B_m P^{\beta} - m/\delta$

where A_m and B_m are constants to be determined, the first term on the right-hand-side is the value of the option to exit, the second term is the value of the option to reactivate the mothballed plant, and the last term is the capitalized maintenance cost assuming the plant remains mothballed forever (Dixit and Pindyck 1994).

Deriving the Trigger Prices

Following Dixit and Pindyck (1994), at each of the four defined switching points, we have smooth-pasting (SP) and value-matching (VM) conditions. SP conditions require tangency of the value functions at the respective trigger prices. The first VM condition states that at the investment trigger price, P_h, the value of the option to enter must equal the value of the active project minus the sunk cost of investment. This implies (with the smooth pasting condition):

(11) $V_0(P_h) = V_1(P_h) - k$ and $V_0'(P_h) = V_1'(P_h)$.

The second VM condition states that at the mothball trigger price, P_M, the value of the option to mothball must equal the value of the mothballed plant minus the sunk cost of mothballing:

(12) $V_1(P_m) = V_m(P_m) - E_m$ and $V_1'(P_m) = V_m'(P_m)$.

The third VM condition states that at the reactivate trigger price, P_r, the value of the option to reactivate must equal the value of the active project minus the sunk cost of reactivation:

(13) $V_m(P_r) = V_1(P_r) - r$ and $V_m'(P_r) = V_1'(P_r)$.

Finally, the last VM condition states that at the exit trigger price, P_l, the value of the option to exit must equal the value of exiting less any sunk costs of exit:

(14) $V_m(P_l) = V_0(P_l) - l$ and $V_m'(P_l) = V_0'(P_l)$.

This simultaneous set of equations results in eight equations with eight unknowns (A_1, B_0, A_m, B_m, P_h, P_r, P_m, P_l) and can be solved for using a numerical analytic approach.

Cost Data and Parameter Estimation

Application of the empirical model requires estimates of μ and σ from corn and ethanol prices, and estimates of firm operational and investments costs; i.e., m, E_m, r, k, l, and w.

Ethanol and Corn Prices

Daily corn prices were collected from the Datastream (2008) representing settlement prices for nearby corn futures contracts on the Chicago Board of Trade. Daily ethanol prices were retrieved from the Bloomberg (2008) representing national average rack (wholesale) prices. To compute the gross margin, we convert the corn price into a dollar per gallon of ethanol equivalent using an average conversion rate of 2.8 gallons per bushel of corn.[3] The data collected encompassed prices from 1 January 1998 through 2 December 2008 (figure 1).

From 1998 through 2004, ethanol prices were in the range of \$1 to \$2 per gallon. Rapid growth in demand pushed daily ethanol prices to a peak in July 2006 at nearly \$3.98. Since then

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[3] Plant data collected revealed no obvious differences in yields across plants of different sizes. In all size categories, yields both above and below our estimate were evident.

prices have remained highly variable and are currently trading at around $2 (figure 1). Relative to ethanol prices, corn prices were relatively less variable early in the sample period but have demonstrated strong price growth from October 2006 through June 2008. More recently, both corn and ethanol prices have dropped precipitously. Since the beginning of 2008, ethanol gross margins have been consistently below $1 per gallon (figure 1).

Given that investors and plant managers do not likely respond to daily price movements, the original data were converted to monthly levels by averaging the daily price quotes within each month. While it is clear from figure 1 that the variation in corn and ethanol prices are quite different, it is the gross margin, or the combined effect of both price series, that is of ultimate importance to firm investor/managers. Note, the use of actual monthly prices in our model does not necessarily imply that managers follow naïve price expectations. The results developed here show the optimal levels of prices in which to change the status of plant operations, however, the specific prices used by managers to compare to the trigger prices may be based on actual or expected prices.

The premise underlying real option pricing is that the stochastic price variable, here the gross margin, follows a random walk; i.e., a stochastic process consisting of a sequence of changes each of whose characteristics (as magnitude or direction) is determined by chance. In addition, the option model assumes that gross margins are log-normally distributed. Accordingly, we use the statistic $d_t = \ln(P_t/P_{t-1})$ to compute the monthly mean and variance parameters. Given that other cost data is on an annual basis, we annualize the monthly statistics resulting in an annually adjusted mean of 0.07 and variance of 0.64.[4] The positive mean rate of drift implies

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[4] Comparatively, the annualized mean and variance estimates for corn and ethanol prices were 0.08 and 0.05, and 0.08 and 0.11, respectively.

gross margins have trended upward over the sample period, a result clearly affected by the abrupt rise in margins in 2006. Given this recent 'bias' to the trend estimate, we initially assume $\mu = 0$.

If gross margins follow a random walk, it follows that the natural log of gross margins has a unit root; i.e., a nonstationary price process, and this can be tested empirically. While price theory suggests that commodity prices should be stationary, the empirical literature have frequently implied the opposite (Wang and Tomek 2007). To see whether the gross margins for ethanol producers followed a random walk in our sample, Augmented Dickey-Fuller (ADF) tests were conducted. Regressions were estimated to test for a random walk with drift and trend, with drift and no trend, and with only a random walk.[5] Lagged dependent variable terms were also included to ensure white noise residuals.

In all cases for corn prices, we cannot reject the null hypothesis of a unit root. These results differ from Wang and Tomek (2007) who found that under most specifications, but not all, a unit root was rejected for monthly corn prices from 1960 to 2005, notably ending prior to the strong price increases. Ethanol prices also show evidence of a unit root in both the random walk and random walk with drift specifications. In relation to fuel prices, Postali and Picchetti (2006) conclude that GBM is a good approximation for crude oil prices, implying the existence of a unit root. Historically, ethanol and crude oil prices have been highly positively correlated giving some support to the GBM assumption towards, at least, ethanol prices. Finally, a unit root is detected in the random walk equation for the gross margin series. Given the empirical results that indicate at least one specification for each variable returns a unit root, it is reasonable to assume that ethanol firms would act as if prices follow a random walk.

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[5] Specifically we model $DP_t = \phi_0 + (\phi_1 - 1)P_{t-1} + \alpha TREND_t + \sum_{i=1}^{n} \beta_i DP_{t-i} + \nu_t$, where $DP_t = P_t - P_{t-1}$, P is the ethanol gross margin, *TREND* is the trend term from 1 to *N*, and DP_{t-i} are lagged dependent variables. The null hypothesis assumes non-stationarity, or $(\phi_1 - 1) = 0$.

Investment and Operating Costs

Investment and operating cost data for corn ethanol plants were taken from the existing literature and represent actual plant data, enterprise budgets, or engineering estimates. Plant costs were grouped by plant size to ascertain any differences in investment and operational decisions to account differences in relative costs. Size classes were broadly defined as less than or equal to 25 million gallons (mgal) per year, 26 - 60 mgal, and more than 60 mgal for the small, medium and large classes, respectively. Table 1 shows the investment and operational cost data collected, along with the value of by-product sales, namely distillers dried grains with solubles (DDGS).

All costs are expressed in dollars per gallon of ethanol and converted to constant 2006 dollars for proper comparison. Capital and depreciation costs were deflated by the Chemical Engineering Plant Cost Index (CECPI 2008), raw material and chemical costs by the Producer Price Index for Chemicals and Allied Products (BLS 2008), utilities and energy costs by Department of Energy prices (DOE 2008), labor and other costs by the *Current Employment Statistics* survey of average hourly earnings of production workers (BLS 2008), and by-product sales by average wholesale DDGS prices (*Feedstuffs* 2008).

The average cost of capital investment costs, as seen in Table 1, declines as plant size increases (Table 2). Capital costs include construction costs (e.g., equipment, engineering, installation) and non-construction costs (e.g., land, start up inventories, working capital). On average, capital costs decrease from $1.95 per gallon for small plants to $1.22 for large plants.

Operating costs were aggregated into four general categories. Chemical inputs include other raw materials and non-corn feedstocks (e.g., denaturants, enzymes, and yeast). Utilities and energy costs include costs for electricity, steam, water, water treatment, and fuel. Capital investments were generally amortized (depreciated) over a 10 to 15 year time horizon. Labor and

Table 1. Capital and Operating Costs, Excluding Corn, for Dry-Grind Corn Ethanol Plants, by Size ($/gal)

			Operating Costs							
Year	Size (mgal/yr)	Capital Cost	Chem. Inputs	Utilities/ Energy	Labor / Other	Depre-ciation	Total	Co-Product	Net Op. Costs	Source
Small Plant										
1998			0.14	0.35	0.26			0.39		Shapouri, Gallagher, and Groboski 2002
1999	25.0	1.49	0.12	0.23	0.15	0.15	0.65	0.36	0.30	McAloon et al. 2000
2000	15.0	2.20	0.15	0.24	0.12	0.14	0.65	0.46	0.19	Whims 2002
2002	<40	2.11	0.11	0.31	0.18	0.21	0.81	0.29	0.52	Shapouri and Gallagher 2005
2004	16.1	2.01	0.12	0.24	0.14	0.18	0.67	0.24	0.43	Rajagopalan et al. 2005
Average	18.7	1.95	0.13	0.27	0.17	0.17	0.74	0.35	0.40	
Medium Plant										
1998			0.18	0.28	0.22			0.30		Shapouri, Gallagher, and Groboski 2002
1999[b]	48.0	1.17	0.16	0.71	0.13	0.11	1.11	0.32	0.79	English et al. 2006
2000	30.0	1.55	0.14	0.22	0.11	0.10	0.57	0.46	0.11	Whims 2002
2000	40.0	1.38	0.13	0.22	0.10	0.09	0.54	0.46	0.08	Whims 2002
2002		1.72	0.11	0.22	0.17	0.17	0.67	0.31	0.36	Shapouri and Gallagher 2005
2004	42.2	1.34	0.12	0.25	0.07	0.12	0.56	0.24	0.32	Rajagopalan et al. 2005
2006	40.0	1.17	0.10	0.26	0.08	0.12	0.55	0.29	0.26	Kwiatkowski et al. 2006
Average	40.0	1.39	0.13	0.31	0.12	0.12	0.69	0.34	0.35	
Large Plant										
1998			0.11	0.21	0.22			0.33		Shapouri, Gallagher, and Groboski 2002
2006	100.0	1.22	0.12	0.37	0.12	0.12	0.73	0.35	0.39	Low and Isserman 2007
Average	100.0	1.22	0.11	0.29	0.17	0.12	0.70	0.34	0.36	

Note: Costs were converted to 2006 dollars by the CECPI (2008) for capital and depreciation costs, by DOE's (2008) energy outlook for utilities and energy, by the Producer Price Index for chemicals and allied products (BLS 2008) for chemical costs, by average hourly earnings of manufacturing workers for labor and other costs (BLS 2008), and by the April distillers dried grains with solubles price (*Feedstuffs* 2008) for co-product sales. Empty cells indicate that the respective costs were not reported. Labor costs of $0.06/gal were added to the labor/other category for English et al. (2006).

Table 2. Baseline dry-grind corn ethanol investment and operating costs, ($/gal).

				Operating Costs		Mothball Costs		
Plant Size	Invest (k)	Exit (l)	Co-Product	Full (w)	Net (w')	Invest (E_m)	Maint. (m)	React. (r)
Small	1.95	-0.49	0.35	0.74	0.40	0.10	0.05	0.20
Medium	1.39	-0.35	0.34	0.69	0.35	0.07	0.03	0.14
Large	1.22	-0.31	0.34	0.70	0.36	0.06	0.03	0.12

Note: Baseline costs assume exit cost (l) = -0.25k, investment mothball cost (E_m) = 0.05k, maintenance mothball costs (m) = 0.025k, and reactivation cost (r) = 0.10k. Operating costs exclude corn feedstock costs.

other costs include labor, supplies, administration, overhead, maintenance, and waste management. Average operating costs (w) were $0.74, $0.69, and $0.70 per gallon for the small, medium, and large plant classes, respectively (table 2). With economies of size in production expected, we would expect to see a monotone reduction in costs as size increases. The fact that average operating costs for the large plant increase modestly from that of the medium plant is likely an artifact of the unequal and limited number of observations in each size category.

By-product contributions were similar across plant sizes and predominantly reflect the sales of DDGS. Some studies discuss the value of other by-products (e.g., CO_2), but were generally not reported. Rajagopalan et al. (2005) present alternative dry-grind technologies with germ and fiber separation equipment that produce alternative by-products and alter ethanol yields. The values of by-products are non-trivial and represent roughly 50% of the non-corn operating costs (table 2).[6] The resulting net operating costs after subtracting out the value of by-product sales (w') are $0.40, $0.35, and $0.36 per gallon for the small, medium, and large plants, respectively.

The overall value of assets if an ethanol plant is liquidated was unknown due to a lack of history with market sales of ethanol processing technology and equipment. We assumed that land

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[6] The high value of ethanol by-products combined with expectations that DDGS prices will be increasingly variable, reduces the validity of the constant-cost assumption for w. While beyond the scope of the present article, a direction for future research is to augment the model by including a separate stochastic variable for ethanol by-products.

would hold its value and production facilities could be retrofitted for alternative uses, producing a liquidation value worth 25% of initial investment costs upon exit (i.e., $l = -0.25k$). The robustness of our results to this assumption is examined later through sensitivity analysis.

The cost of mothballing and maintaining a mothballed ethanol plant was also unkown. In a 2005 press release, Terra Industries, Inc. announced that it would cost $5 million to mothball a 225 mgal/year methanol facility (*Chemical Engineering Press* 2005). Linearly extrapolating our investment costs (table 2) out to this size of plant would imply a sunk cost (E_m) of around 3%. Given the optimistic nature of most press releases, we assume a slightly higher estimate of 5%. Soontornrangson et al. (2003) cite mothball maintenance costs (m) for an electrical power plant at 1% of capital costs, or around 20% of operating costs. Applying the 20% relationship to our estimates in table 2 results in maintenance costs of around 5% of capital costs. Conservatively, we select a mid-range estimate of 2.5%. Reactivation costs (r) were assumed double that of the initial cost to mothball, or 10%. All baseline parameters are displayed in table 2. Finally, we assume a discount rate (δ) of 8% to reflect a relatively higher credit risk of ethanol plant investment.

Empirical Results

The estimated cost and margin parameters were substituted into the 8-equation system, (11) through (14) above, and solved for using Matlab software (version 7.5). We begin by discussing the results of the baseline solution using input parameters from table 2. This is followed by sensitivity analysis of the results over key cost and margin parameters.

Baseline Solutions

Ethanol gross margins by plant size that would encourage entry in (P_h) and exit from (P_l) ethanol processing at the baseline parameters (Table 2) are shown in Table 3. Also included are

Table 3. Gross margin trigger prices using net present value and real option analyses.

	Plant Size		
Cost or Trigger Price	Small	Medium	Large
Investment Cost (k)	1.95	1.39	1.22
Net Operating cost (w')	0.40	0.35	0.36
Entry, P_h	1.78	1.39	1.33
Reactivate, P_r	0.79	0.66	0.66
Entry (NPV), W_h	0.55	0.46	0.45
Exit (NPV), W_l	0.43	0.37	0.38
Mothball, P_m	0.18	0.17	0.18
Exit, P_l	0.17	0.14	0.13

Note: NPV = Net Present Value, exit cost (l) = -0.25k, investment mothball cost (E_m) = 0.05k, maintenance mothball costs (m) = 0.025k, and reactivation cost (r) = 0.10k. Net operating costs exclude corn feedstock costs.

trigger prices that correspond to a NPV analysis (W_h and W_l, respectively). Margins that trigger entry drop with increases in firm size given decreased unit capital investment costs. Relative to the small plant entry trigger ($1.78), entry triggers are 22% and 25% lower for medium ($1.39) and large ($1.33) plants, respectively.

Exit costs follow a similar decreasing pattern with firm size; relative to the small plant exit trigger ($0.17), exit triggers are 18% and 24% lower for medium ($0.14/gal) and large ($0.13) plants, respectively. Note that while larger plants exhibited slightly higher net operating costs than medium plants, exit triggers are also affected by the options and costs to mothball and reactivate. Given that these costs are based on a fixed percentage of capital investment costs (k) and unit capital costs decrease with plant size growth, lower mothball costs for the larger plant class more than offset its relatively higher operating costs, resulting in a lower overall exit price.[7]

The importance of considering price uncertainty in this case can be evaluated by comparing the NPV and real options results. Entry (exit) prices considering real options are, on

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[7] When mothballing is not allowed, trigger prices are $1.74, $1.36, and $1.30 for entry, and $0.18, $0.16, and 0.17 for exit, for the small, medium, and large plants, respectively.

average, 207% (63%) above (below) their NPV counterparts (table 3). With the baseline assumption of a 25% liquidation value, the NPV entry and exit price triggers are relatively close – a spread of only \$0.07 to \$0.12. However, with the addition of real options, the entry-exit price spreads range from \$1.20 to \$1.61. Idle firms will wait considerably longer to invest in order to take advantage of possible gains from higher margins in the future, while currently operating firms will wait longer before exiting with the expectation that margin prices will improve.

Given that mothball costs are based on fixed percentages of capital investment, differences in trigger prices across plant sizes are less dramatic than for entry and exit. Firms will mothball plants when gross margins drop to a range of \$0.17 and \$0.18 and later reactivate if margins increase to between \$0.66 and \$0.79 (table 3). The slightly higher operating costs for the large plant result in a mothballing trigger at prices roughly the same as that for the small plant, but lower initial investment costs imply that the larger plant can reactivate sooner. The relatively high liquidation value (-0.25*k*) compared with mothballing and reactivation costs (ranging from 0.025*k* to 0.10*k*) result in trigger prices to mothball and exit that are relatively close.

Using the medium size plant results as approximate industry-averages, Figure 2 plots the computed trigger margins overlaid with the number of ethanol plants that are currently in operation or under construction (RFA, 2008) to evaluate actual changes in plant numbers when compared with times that price triggers are met. Based on the annual plant numbers, actual plant exits did not occur or at least the aggregate number of plants increased monotonically over the sample period. However, relative to the NPV trigger prices, plant exits would have been expected to occur in the late 1990s, and in some periods of 2002 and 2003. In contrast, under the real options framework, at no time during the sample period, were mothballing or exit trigger prices reached.

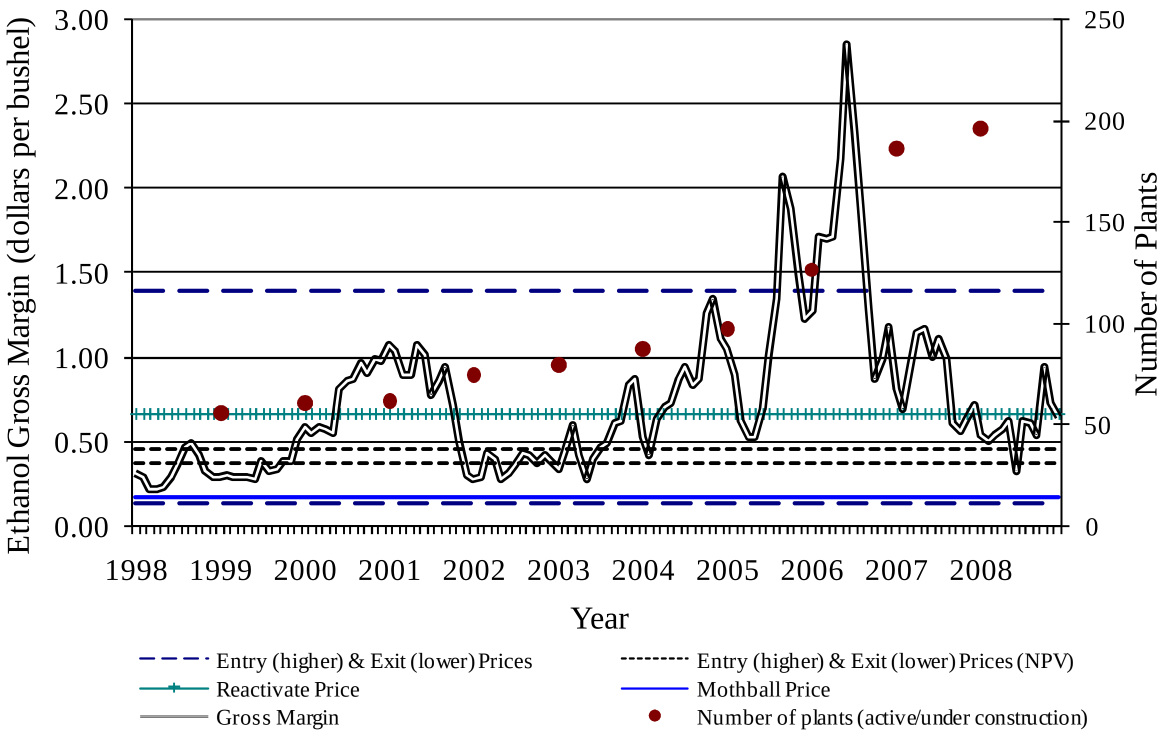

Figure 2. Ethanol gross margins, plant numbers, and real option and NPV trigger prices, medium-size ethanol plant, baseline parameters

The real option margin triggers imply that new entrants into the industry would not occur until 2006 (figure 2). While actual plant numbers increased annually during the period of 1998 to 2005 (and were consequently above the NPV entry trigger), the rate of change was modest compared with increases more recently. Our results are consistent with the fast growth in plant numbers exhibited in 2006 and 2007. Also, as margins drop below the entry trigger margin in 2007 and in 2008, the rate of increase in the number of plants slowed precipitously.

Looking forward, if reductions in gross margins continue to be realized, mothballing and plant exits may well become an economic reality. As a short-run example, flooding in areas of Iowa and Illinois in June 2008 resulted in estimated margins in the $0.20 to $0.30 range, well below the NPV exit prices, and close to or at the real option mothballing and exit price triggers.

Sensitivity Analysis

Clearly, the results are conditional on a number of factors, including the sample period and assumed discount rate. If the assumed drift rate, μ, was set at its estimated value of 0.07, exit and entry margin triggers would both decrease, approximately 4% and 6%, respectively. Intuitively, this makes sense – if there is an expected upward trend in gross margins, investors today would be willing to enter sooner and, once in, would delay exit given an expected positive margin trend. Conversely, a higher discount rate (δ), ceterus paribus, will increase both the entry and exit trigger prices as the opportunity cost to alternatively invest funds increases, approximately 2% and 3% for each 100 basis points, respectively

We also evaluated the sensitivity of our results to the level variability in gross margins. As this variability increases, entry and reactivation trigger prices increase substantially, particularly for new investment, and decreases the trigger prices to exit and mothball (figure 3, panel a). With higher upside potential in prices, it is optimal for firms to further delay entry (or reactivate) until more favorable prices are realized, while existing plants will stay in operation (or mothballed) longer with an increased expectation that prices will improve. It is also true that as margin volatility decreases, the option to mothball makes less sense. All else held constant, at a margin variance below $\sigma^2 = 0.18$, it would be optimal to simply exit directly as prices decline, rather than mothball to a suspended state first. As margin variation decreases below this point, the odds of improved margin performance in the future is so low, it would be optimal to simply exit the industry and invest the liquidated funds elsewhere.

As liquidation values decline, ceterus paribus, entry (exit) price triggers increase (decrease) (Figure 3, panel b). To compensate for higher exit costs, investors will wait longer to enter until margins are increased sufficiently to compensate, while active firms will wait longer

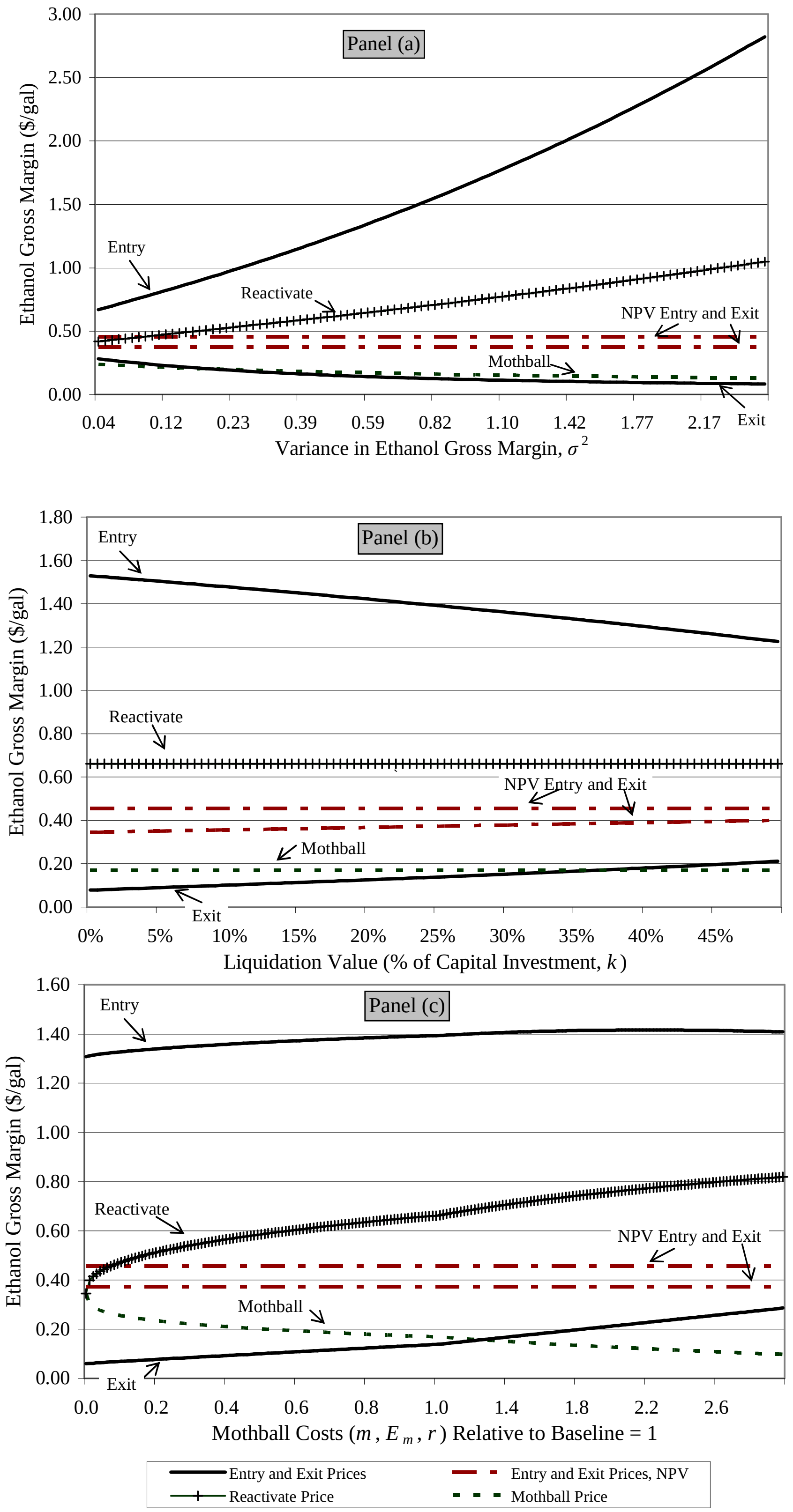

Figure 3. Adjustments in Real Option Trigger Prices with respect to Changes in Gross Margin Variation (a), Liquidation Value (b), and Mothball Costs (c).

to get out avoiding the higher cost of exit. Furthermore, at liquidation values above 37%, if prices decline sufficiently, it is optimal to directly exit than to go into a mothballed state first. As more of a firm’s initial investment is able to be recouped upon exit, it is increasingly beneficial to take those funds and reinvest elsewhere rather then delay retrieval of those funds in a mothballed state.

Finally, Figure 3 (panel c) demonstrates the impact on trigger margins as the costs to mothball (and reactivate) changes, assuming that all mothballing costs (E_m, m, and r) move proportionately. As mothballing costs increase, trigger margins for exit increase since as the cost to suspend operations increases, the costs to exit become relatively more inexpensive. Likewise, an active firm will wait longer to go into this relatively more expensive state and, once mothballed, will wait longer to reactivate to active production. Furthermore, when the mothballing costs increase 25% above baseline values, ceterus paribus, as gross margins decrease it does not make sense to consider mothballing at all.

Conclusions

Entry and exit ethanol gross margin triggers were computed using net present value and real options frameworks. Firm size was explicitly considered, generally revealing lower margin triggers as plant size grew, essentially accounting for economies of size in production. For a large plant size and moderate liquidation costs, optimal firm entry is expected when ethanol gross margins exceed $1.33 per gallon and exit would commence when gross margins drop below $0.13. However, in the face of declining prices, plants would first suspend operations and mothball their plant at prices of $0.18, and reactivate if prices rebounded to $0.66.

While gross margins reached a peak of nearly $3 per gallon in 2006, more recent margins are hovering around $0.50 or less. If margins continue to decrease as they have in 2007 and

2008, delayed investments and construction plans may progress to suspensions and/or exits of currently operating facilities. In addition, continued growth in the variability of ethanol margins will lead to delays in new plant investments and delays in exits of currently operating facilities.

Relaxing some of the assumptions in the base model may more accurately reflect risk and uncertainty in the ethanol production. For example, expanding the model to include additional sources of uncertainty and, thereby, additional stochastic variables (e.g., by-product sales, energy prices) would be a reasonable extension (Nostbakken, 2006), albeit at the cost of increasing the complexity of the models to be solved. In addition, the future level and existence of ethanol subsidies are not known with certainty. Incorporating probabilities of expected future subsidies may be an important consideration for investment and operation decisions (Viju, Kerr, and Nolan 2006). Finally, to the extent that alternative technology becomes viable (e.g., cellulosic ethanol) the model can be adapted to estimate and compare the results across alternative investments.

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