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Abstract

A real option analysis of dry-grind corn ethanol plants compared to a standard net present value analysis (NPV) shows that the option values increase entry prices and lower exit prices of investment and disinvestment considerably. For a large plant, the gross margin of ethanol price over the corn price for a gallon of ethanol using NPV shows that entry will occur with a $0.45 margin and shutdown will occur at a $0.38. Under a real options framework, the margins for entry and exit become $1.33 and $0.13, respectively. Under baseline conditions, a large operating plant would become mothballed at $0.18 and reactivate if margins rebounded to $0.66. Growth in the variability of ethanol margins will delay new plant investments, as well as exits of currently operating facilities.

JEL Classification: D21, D81, Q4

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

Production and demand for renewable sources of energy are dramatically impacting U.S. commodity markets. Ethanol production (primarily from corn) in the U.S. reached nearly 6.5 billion gallons in 2007, an increase of over 3 billion gallons since 2004 (RFA 2008). Despite this rapid increase, there is evidence that the industry was stepping up the pace of expansion, with production expected to top 10 billion gallons by 2009 (Wescott 2007). 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).

More recent expansion has been tempered by changing market conditions. Strong increases in corn prices relative to the price of ethanol imply tighter operating margins and are contributing to the delayed development of some planned corn ethanol facilities (Feinman 2007). 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 in the first part of 2008 were around $0.50 or less.

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 the industry 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 until recently this argument carried merit, large reductions in margins and substantial increases in margin volatility bring the likelihood of firm exits or operational suspensions a current reality.

From this more thorough 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

Entry and Exit Decisions under Uncertainty

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 assumptions concerning the characteristics of the investment. First is 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, we include these costs in the firm's operating costs.

Now, suppose you 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.

Under general conditions, an active firm will choose to mothball before it exits. However, in some cases it may not be optimal to consider mothballing at all. For example, 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 proceed on the assumption that when price falls to a certain point, mothballing is used. 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 in the future if activated. If current investors 'sold' the project and instead invested the proceeds, they would earn $\delta V_0(P)$. Equilibrium in the asset market requires:

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

As shown by Dixit and Pindyck (1994), this homogenous, second-order, ordinary differential equation has the solution:

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

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 and value-matching conditions. Smooth-pasting conditions require tangency of the value functions at the respective trigger prices. 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 $V_0'(P_h) = V_1'(P_h)$.

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, or:

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

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, or:

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

Finally, 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, or:

(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 a conversion rate of 2.8 gallons per bushel of corn.[3] The data collected encompassed prices from 1 January 1998 through 18 June 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 prices have retreated precipitously and are currently in the range of \$2 to \$2.50 (figure 1). Relative to ethanol prices, corn prices were relatively less variable early in the sample period but have demonstrated strong price growth since October 2006. With corn and ethanol prices moving in opposite directions, ethanol gross margins dropped sharply from its high in July 2006 to a low of less than \$0.50 in June 2008 (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.

The premise underlying real option pricing is that the stochastic price variable, here the gross margin, follows a random walk. 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 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 $\mu = 0$.

While price theory suggests commodity prices should be stationary, the literature have frequently implied the opposite (Wang and Tomek 2007). In fact, Wang and Tomek (2007) conclude that one should have a "healthy skepticism about the existence of unit roots in time series of nominal, spot prices for agricultural commodities." Alternatively, Postali and Picchetti (2006) conclude that GBM is a good approximation for crude oil prices. Historically, ethanol and crude oil prices have been highly positively correlated giving some support to the GBM assumption towards, at least, ethanol prices. In addition, recent market adjustments have led to increased correlation between corn and oil prices.

While not shown, Augmented Dickey-Fuller (ADF) tests were conducted to test for a random walk in the ethanol gross margin. 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 included to ensure white noise residuals. Surprisingly, in all cases for corn prices, we cannot reject the null hypothesis of a unit root, supporting the argument that corn prices are becoming more and more priced in relation to oil price movements. These results differ from Wang and Tomek (2007) who find 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. Finally, in only the random walk equation did the gross margin series exhibit a unit root. Given the empirical results that indicate at least one specification for each variable returns a unit root, we argue that it is reasonable to assume that ethanol firms would act as if prices follow a random walk.

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 when accounting for changes 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).

As expected, capital investment costs decline with increases in plant size (table 1). 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 the 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 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.

Given the specialized nature of the ethanol processing technology and equipment, the overall liquidation value of assets upon exit is unknown. Given that land holds it value and production facilities could be retrofitted for alternative uses, we initially assume a 25% liquidation value upon exit (i.e., exit costs = $-0.25k$).

Little information is available on mothballing costs for ethanol facilities. 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%. Conservatively, we select a mid-range estimate of 2.5%. 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 would imply a sunk cost (E_m) of around 3%.

Given the optimistic nature of most press releases, we assume a more conservative estimate of 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 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 trigger prices that correspond to a NPV analysis (W_h and W_l, respectively). Entry price triggers 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 pattern where, 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. While larger plants exhibited slightly higher net operating costs than medium plants, exit costs 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 per unit 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 with respect to ethanol gross margins cannot be understated. Entry (exit) prices considering real options are, on average, 207% (63%) above (below) their NPV counterparts (table 3). With the relatively optimistic baseline assumption of a 25% residual 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 a fixed percentage of capital investment, irrespective of plant size, the changes in trigger prices across size classes are less dramatic than exhibited 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, depending on class size (table 3). Medium size plants will delay mothballing, relative to the small and large plants, until margins are slightly lower, and will reactivate sooner. 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 ($-0.25k$) compared with mothballing and reactivation costs (ranging from $0.025k$ to $0.10k$) 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). Based on the annual plant numbers, actual plant exits did not occur or at least the total 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.

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, 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. 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 drift rate, μ, is not adjusted to zero, but remains at the estimated value of 0.07, both the exit and entry trigger values would 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

As the variability in gross margin 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 the case that as margin variability decreases the option to mothball makes less economic 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.

For all else held constant, entry (exit) price triggers increase (decrease) as liquidation values decline (figure 3, panel b). To compensate for expected higher exit costs, investors will wait longer to enter until margins are increased sufficiently to compensate, while active firms will wait longer 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

Strong growth in the demand for agricultural commodities are evident in the strong increases in prices and price variability of U.S. grains and oilseeds. Federal and state incentives have increased the demand for renewable sources of energy, resulting in aggressive expansion and investment in renewable fuel production, primarily corn-based ethanol. While produced for years, fast growth over the past three years has been both a haven and heartache for investors in corn ethanol facilities. Record-high returns in 2006 and 2007 have vanquished in the face of precipitous drops in gross margins when continued strong growth in corn prices has not been compensated in ethanol markets.

Entry and exit ethanol gross margin triggers were computed using both net present value and real options frameworks. Firm size was explicitly considered, generally revealing lower margin triggers as plant size increased, essentially accounting for economies of size in production. Considering 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 be more reflective of true investor options, and more accurately reflect risk and uncertainty in the ethanol production. 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 technologies become viable (e.g., cellulosic ethanol) the model can be adapted to estimate and compare the results across alternative investments.

Footnotes

[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 indirect route would be cheaper than investing in an operational project upfront (Dixit and Pindyck 1994).

[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.

[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.

[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.

[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 $(\phi_1 - 1) = 0$.

[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 logical direction for future research is to augment the existing model by including a separate stochastic variable for ethanol by-products.

[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.

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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)

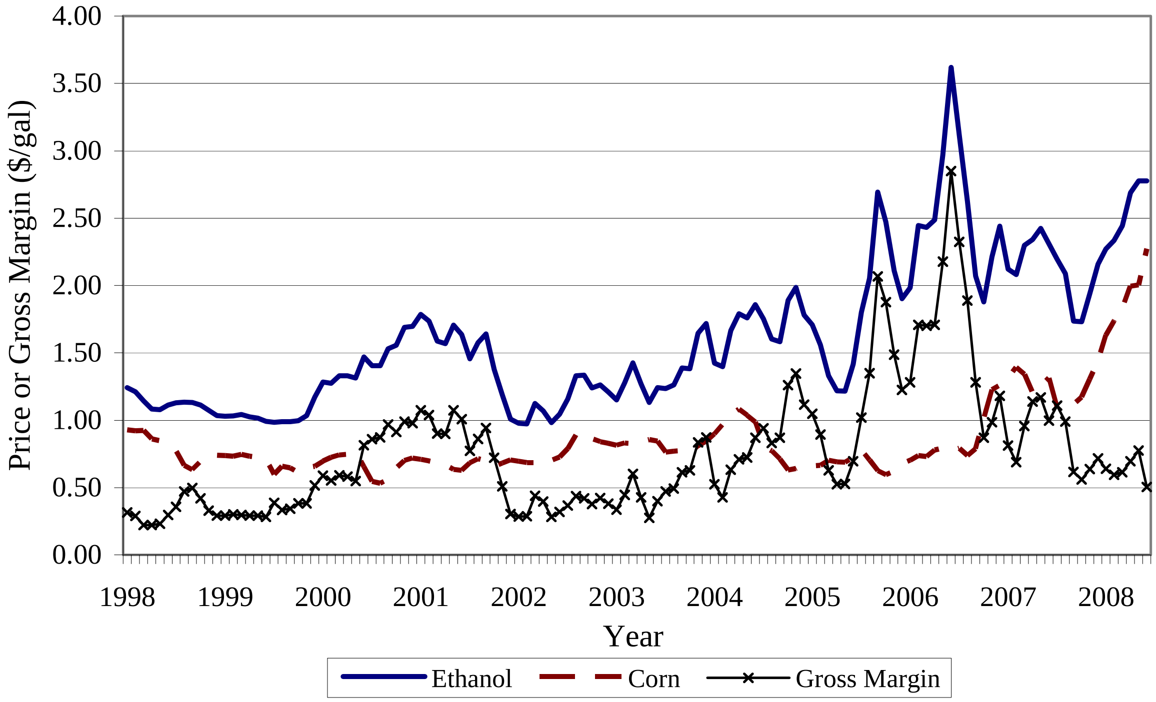
	Investment	Exit	Co-	Operating Cost		Mothball Costs		
Plant Size	Cost (k)	Cost (l)	Product	Full (w)	Net (w')	Invest.(E_m)	Maint.(m)	React.(r)
Small	1.95	-0.49	0.35	0.74	0.40	0.10	0.05	0.20
Medium	1.39	-0.35	0.34	0.69	0.35	0.07	0.03	0.14
Large	1.22	-0.31	0.34	0.70	0.36	0.06	0.03	0.12

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.

Table 3. Gross Margin Trigger Prices Using Net Present Value (NPV) and Real Option Analysis, Dry-Grind Corn Ethanol Plants, by Size

	Plant Size		
Cost / 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: 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.



Sources: Datastream (2008), Bloomberg (2008); assumes 2.8 gal ethanol yield per bushel of corn

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

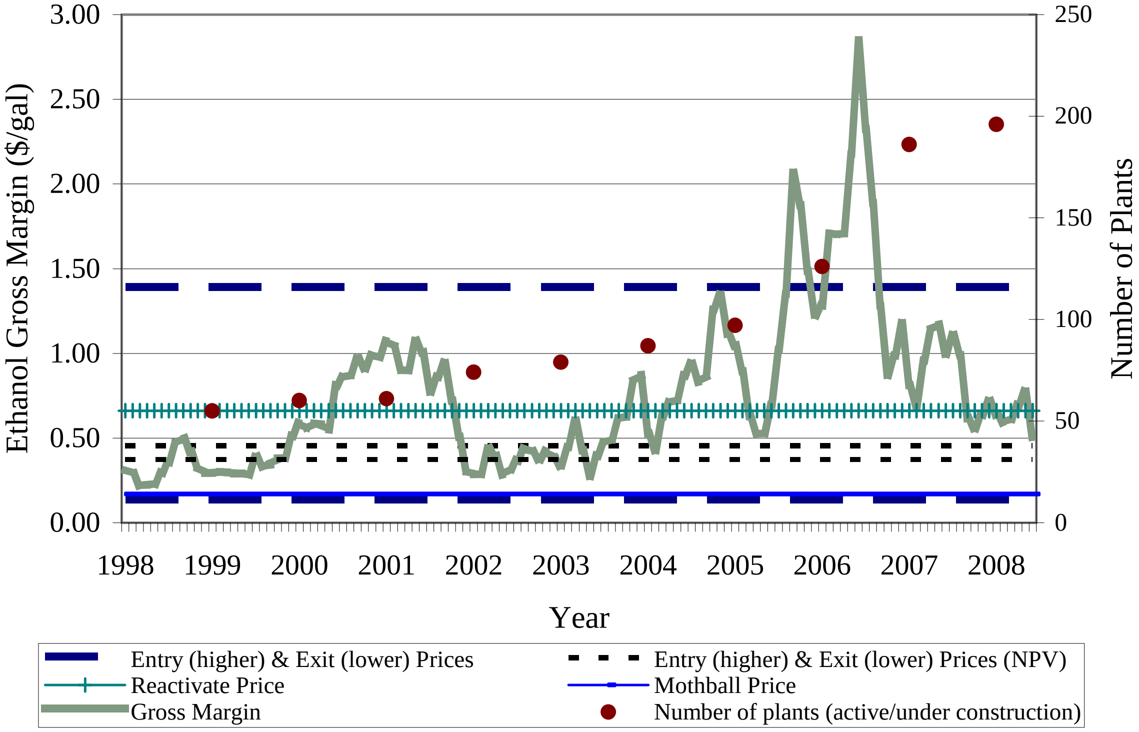


Figure 2. Ethanol gross margins, plant numbers, and real option and NPV trigger prices, medium-size ethanol plant, baseline parameters

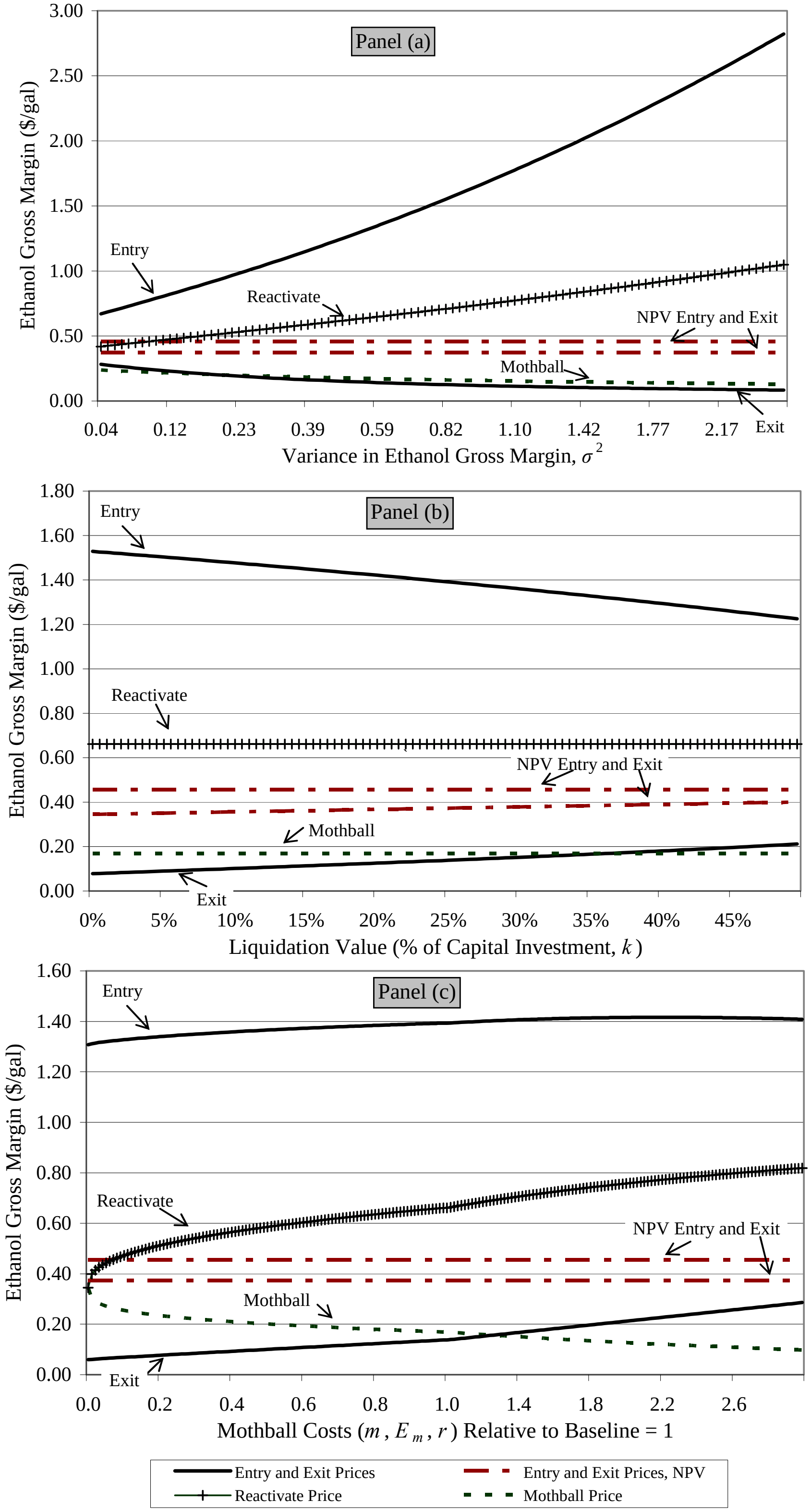


Figure 3. Adjustments in Real Option Trigger Prices with respect to Changes in Gross Margin Variation (a), Liquidation Value (b), and Mothball Costs (c)