

# OPTIMAL FIRM ENTRY AND EXIT IN THE ETHANOL INDUSTRY

by

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(Under the Direction of Berna Karali)

## ABSTRACT

The objective of this thesis is to evaluate entry and exit investment decisions for an ethanol plant in the state of Georgia under a real options approach (ROA) and compare the results to those obtained under the traditional net present value (NPV) approach. Dixit and Pindyck's model of a firm's entry and exit decisions under irreversible investment and price uncertainty is used to model entry and exit ethanol margin thresholds.

We evaluate entry/exit decisions for two different size conventional ethanol plants: a 50 million gallon/year and a 100 million gallon/year plan under both the ROA and NPV approaches. Results suggest that by considering the stochastic nature of the ethanol margin, the irreversibility of investment in an ethanol plant, and the possibility to delay the investment /disinvestment decisions, the ROA yields more "cautious" thresholds- the gap between entry and exit margins is shown to be consistently larger with ROA.

INDEX WORDS: Ethanol, Investment, Net Present Value, Real Options, Uncertainty.

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B.S.A., The University of Georgia, 2007

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment  
of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2011

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## DEDICATION

To M&M, for making it possible.

## ACKNOWLEDGEMENTS

A special and heartfelt thanks to Dr. Karali for her continued support and encouragement.

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## CHAPTER 1

### INTRODUCTION

Economic growth and social progress over the course of human history have largely depended on the availability of and ability to harness energy. According to the U.S. Department of Energy, fossil fuels provide more than 85% of all the energy consumed in the United States. However, rising fossil fuel prices, energy security issues, as well as environmental and health concerns have led to a general rethinking of the current sourcing and uses of traditional fossil fuels. This, in turn, has sparked a growing interest in alternative sources of energy that are economically, socially, and environmentally sustainable.

In their Annual Energy Outlook 2009, the U.S. Energy Information Administration finds strong growth in the use of renewable fuels---including wood, municipal waste, and other biomass in the end-use sectors; hydroelectricity, geothermal, municipal waste, biomass, solar, and wind for generation of electric power; ethanol for gasoline blending; and biomass-based diesel. In 2009, consumption of these marketable fuels increased by as much as 3.3 percent. According to the USDA Economic Research Service, ethanol produced mainly from corn is currently the principal source of bioenergy in use as a fuel additive or as an alternative to petroleum fuel in the United States.

Therefore, it is not surprising that the ethanol industry has been the focus of attention of a variety of academic and private studies. The state of Georgia, where three ethanol plants are currently located, has captured the interest of academics and investors; and a number of feasibility and economic impact analysis on the establishment of ethanol plants have been

conducted. In a 2007 study “The Economics of Ethanol Production in Georgia”, the Center for Agribusiness and Economic Development at the University of Georgia examines 50 and 100 million gallon ethanol plants to determine their economic feasibility and estimated profitability. In their study, the authors conduct a traditional financial feasibility calculation and find that the 100 million gallon plant is economically feasible and that, given high enough ethanol prices and low enough corn prices, both plants could have profitable operations. The analysis assumes an ethanol price of \$1.75/gallon and corn costs of \$2.80/bushel.

The United States Department of Agriculture, in its February 2011 edition of the World Agricultural Supply and Demand Estimates, states that “corn used for ethanol is projected 50 million bushels higher on a higher-than-expected November final ethanol production estimate and weekly ethanol data that indicate record output for December and January”. According to this same report, the 2010/11 marketing year average farm price for corn is projected at \$5.05 to \$5.75 per bushel. Data obtained from the Agricultural Marketing Resource Center indicates that as of January 4<sup>th</sup>, 2010, ethanol prices ranged from \$2.1/gallon to \$2.35/gallon across an average of 5 states (Wisner and Johanns, 2011). Clearly, these price estimates are very different from the estimates used for the “Economics of Ethanol Production in Georgia” analysis. Thus, the results from an analysis such as the one mentioned above, that do not incorporate price uncertainty into investment decisions can easily be deemed inadequate when prices change significantly.

The net present value (NPV) approach to evaluating capital budgeting decisions continues to be used by managers to choose investments with adequate cash flows and satisfactory returns. A project’s NPV represents “the sum of the present value of the expected future cash flows obtained from the investment and the salvage value of the project at maturity, if any, deducted from the initial investment cost” (Lin and Shih, 2004). The NPV approach,

however, assumes that the investment decision is static---projects are either pursued or dismissed. However, most, if not all, real life projects do not meet the “irreversibility” assumption and the possibility of delaying a project is one of the very important characteristics of most investments (Dixit and Pindyck, 1994). Additionally, the NPV approach assumes that the underlying conditions remain static and certain in the future, but this assumption can prove costly in the context of cash flow uncertainty.

The real options approach (ROA) seeks to incorporate the existence of managerial flexibility and cash flow uncertainty into capital budgeting decisions. The ROA makes an investment opportunity analogous to a financial call option: an investment opportunity gives the investor “the right, for some specified amount of time, to pay an exercise price and in return receive an asset that has some value” (e.g. an investment project). In short, this approach recognizes the option value of waiting for better information (Dixit and Pindyck, 1994).

We examine ethanol plant investment and abandonment decisions in the state of Georgia under a framework of investment under uncertainty. We study entry and exit decisions for the 50 million gallon and 100 million gallon ethanol plants under a ROA and under the more traditional NPV approach. Results indicate that, under the ROA, investors require stronger price stimuli to make investment or disinvestment decisions. By incorporating managerial flexibility and price uncertainty into the model, the inaction gap, the gap between the entry trigger margin the exit trigger margin, is larger than under a conventional NPV approach.

Chapter 1 provides an overview of the ethanol industry including ethanol production in the U.S. and a discussion on ethanol production in the state of Georgia. Chapter 2 develops the theoretical framework behind the NPV and the ROA approaches. It also presents a literature review of the ROA within the field of agricultural economics. Chapter 3 provides a description

of the investment and operating costs of the ethanol plants. Additionally, it presents and details the price data and parameters used in the estimation of the investment and abandonment threshold margins. Chapter 4 reports the entry and exit threshold margins benchmark results and includes sensitivity analyses on key variables: capital costs, drift, volatility, and entry and exit costs parameters. Chapter 5 includes conclusions and final remarks.

## **1.1 The Ethanol Industry**

Ethanol is a clear, colorless alcohol fuel made by fermenting the sugars found in crops such as corn, wheat, sugar beets, and sugar cane. The use of ethanol as fuel is not new; almost 90 million gallons a year were produced in the 1850's when it was used mainly as lamp fuel. At the beginning of the U.S. Civil War, the Union Congress established a \$2 per gallon excise tax on liquor to help finance the war. This added cost caused people to substitute methanol and kerosene as their lamp fuel of choice.

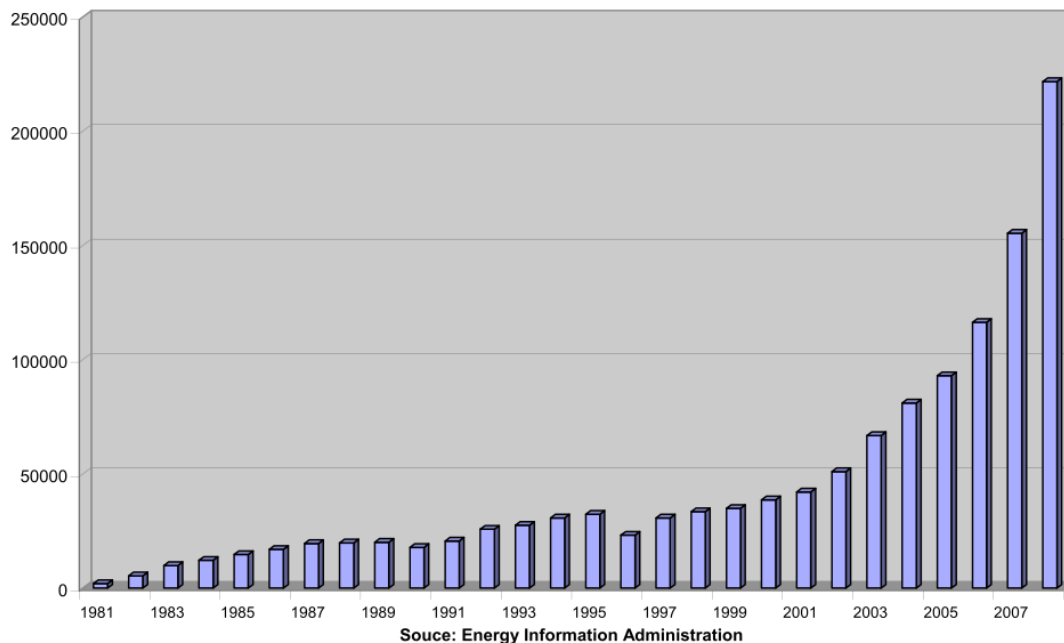
In 1906, ethanol's use as fuel became viable again due to the repeal of the liquor excise tax. Then, in 1908 Henry Ford designed the "Model T" Ford, a vehicle which ran on a mixture of gasoline and alcohol. Use of ethanol increased dramatically during World War I and by the end of the war in 1918, production had reached 50 million gallons per year.

In the 1920's the use of ethanol transitioned from fuel to fuel-additive. Standard Oil began adding ethanol to gasoline to increase octane levels and reduce engine knock. The use of ethanol in this fashion increased steadily until the end of World War II. After 1945, especially low oil prices caused ethanol demand and production to decrease significantly. It was not until the oil crisis in 1973 that the ethanol industry experienced a revival and ethanol became a key element in the energy policy and outlook for many countries, including the United States (Bungert and Darnay, 2008).

### 1.1.a Ethanol Production in the U.S.

As shown in Figure 1, production of fuel ethanol in the U.S. has shown a significant positive trend since the 1980's. Along with production growth, ethanol's presence in the U.S. gasoline supply has also steadily increased. Several economic and political factors have played a role in the ethanol boom including rising fossil fuel prices, the elimination of methyl tertiary butyl ether (MTBE) as an oxygenating gasoline additive, Federal tax credits, and the Renewable Fuel Standard (RFS) program.

Figure 1. U.S. Oxygenate Plant Production of Fuel Ethanol (Thousand Barrels)



The recently passed Energy Independence and Security Act of 2007 (EISA 2007) contains the RFS program, which represents a considerable long-term commitment to increase agricultural biofuels. The RFS stipulates the total level of biofuels to be used until the year of 2020 and also marks levels for fuels to be produced from key feedstock categories. It is expected that corn-based ethanol production will continue to grow, to the extent that 15 billion gallons will

count toward the 2015 RFS---over 60 percent above the 9 billion gallons produced in 2008 (Malcolm, Aillery, and Weinberg, 2009).

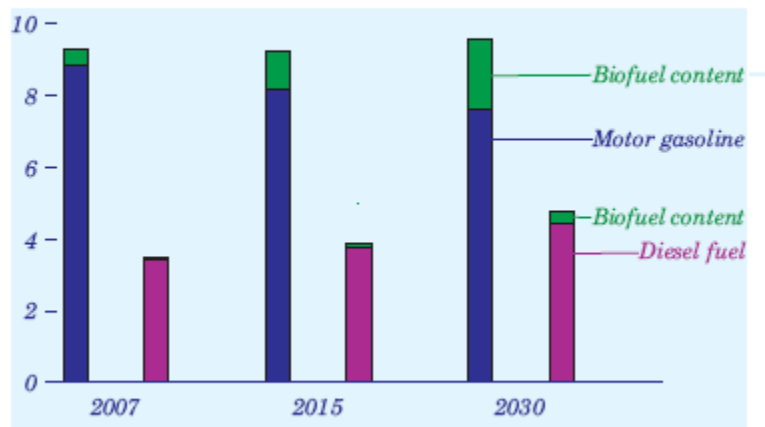
Additionally, as a requirement of EISA 2007, the National Highway Traffic Safety Administration (NHTSA) must raise the Corporate Average Fuel Economy (CAFE) standards for passenger cars and light trucks. The goal is to reach an average tested fuel economy of the combined fleet of all new passenger cars and light trucks sold in the country in 2020 equal or exceeding 35 miles per gallon. The improved fuel efficiency represents a 34 percent increase over today's fleet average of 26.4 miles per gallon (NHTSA, 2007). In order to meet the CAFE standards a number of incentives to manufacturers have been created, including granting credit toward meeting the CAFE standards by producing alternative-fuel vehicles.

The RFS in EISA 2007 and the CAFE standards, coupled with higher fossil fuel prices are expected to precipitate a distributional shift in the use of different types of fuels. Biofuels such as ethanol and biodiesel are expected to increasingly displace fossil fuel use in the transportation sector (see Figure 2). In the AEO 2009, it is estimated that U.S. production of biofuels will grow from less than 0.5 million barrels per day in 2007 to 2.3 million barrels per day in 2030. The largest share of this growth is fueled by ethanol; its use for gasoline blending is predicted to grow to more than 0.8 million barrels per day and its consumption in E85<sup>1</sup> to increase to 1.1 million barrels per day in 2030.

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<sup>1</sup> E85 is ethanol blending into gasoline at 85 percent by volume.

Figure 2. Biofuel content of U.S. motor gasoline and diesel consumption, 2007, 2015, and 2030 (million barrels per day)



Source: AEO2009, EIA.

To meet demand, ethanol is produced mainly in biorefineries located in the Midwest using corn and other starchy crops (see Figure 3). Technology has been created and is currently being developed to produce ethanol from cellulosic material, including switchgrass and poplar. The AEO 2009 finds that the number of operating corn-based ethanol plant in the U.S. is currently over 150, with a total production capacity of more than 10 billion gallons per year. The Renewable Fuels Association estimates that there are a total of 201 nameplate biorefineries as of April 2010, with an estimated operating production of 12.6 billion gallons per year.

Figure 3. Biorefineries in the U.S.



### 1.1.b Ethanol Production in Georgia

Biofuel production has been concentrated on the Midwest due to the readily available biomass (mainly corn and soybeans) for use as feedstock and also because of the existence of well developed rail lines that make it possible to distribute the fuels to the rest of the country. In the context of ethanol production in the state of Georgia, a number of studies have been conducted by the Center for Agribusiness and Economic Development (CAED) at The University of Georgia analyzing the feasibility of ethanol production in the state.

Investors' interest in establishing an ethanol production facility in Georgia are motivated in part by the 1990 Clean Air Act Amendments, which established the Federal Reformulated Gasoline (RFG) program. This program requires that gasoline sold for consumption in areas

which do not meet federal standards for air quality must contain a minimum of 2 percent oxygen by weight. Ethanol is one of two main oxygenates for gasoline, the alternative, MTBE, has been partially or fully banned in 21 states (EPA, 2007). If the MTBE ban extends to additional states, the market for ethanol will likely experience substantial growth.

Furthermore, the metro Atlanta area has been classified as a region with “severe” air quality and it therefore falls under the RFG requirements. Atlanta consumes approximately 3 billion gallons of gasoline per year, which results in a potential ethanol market of 300 million gallons under the RFG (Shumaker et al., 2007). This market size is enough to entice investors to look into the feasibility of ethanol production within the state.

There are, however, a number of drawbacks to consider: the state of Georgia faces a corn deficit---it consumes more of the crop than it produces. The CAED at The University of Georgia estimates that corn consumption in the state is in excess of 205 million bushels while USDA estimates the Georgia 2009 corn crop at around 52 million bushels. It is also estimated that a conventional ethanol plant producing 100 million gallons per year would require an additional 36 million bushels of corn. As a result of the corn deficit, Georgia would need to import additional corn from corn-surplus states, thus bringing transportation issues, such as cost and mode of transportation into play. On the other side, savings could be realized since a biorefinery located in Georgia would remove the cost of transporting the finished product (ethanol) from the producing states into Georgia.

According to data from the Renewable Fossil Fuels Association, as of February 3<sup>rd</sup> of 2011, there are 3 ethanol plants in the state of Georgia. The following table provides the available information on the type of plant, plant location, nameplate capacity, and operating production.

| <b>Table 1. Ethanol Plants in the State of Georgia</b> |                 |                  |                                    |                                      |
|--------------------------------------------------------|-----------------|------------------|------------------------------------|--------------------------------------|
| <b>Company</b>                                         | <b>Location</b> | <b>Feedstock</b> | <b>Nameplate Capacity<br/>(mg)</b> | <b>Operating<br/>Production (mg)</b> |
| Range Fuels                                            | Soperton, GA    | Woody Biomass    | *Under Construction*               |                                      |
| Southwest Georgia<br>Ethanol                           | Camilla, GA     | Corn             | 60                                 | 60                                   |
| Wind Gap Farms                                         | Baconton, GA    | Brewery Waste    | .4                                 | .4                                   |

It is also worth mentioning that Southwest Georgia Ethanol filed a Chapter 11 petition in February 2011 in Albany, Georgia. According to Bloomberg Financial news, in its petition, the company listed assets of \$164.7 million and debt of \$134.1 million. Southwest Georgia Ethanol indicated that its financial troubles were caused by the shrinking margin they are able to obtain for the ethanol they produce; the price of corn is high compared with the price of ethanol.

It is within this context that the application of enhanced capital budgeting techniques used for analyzing ethanol plant investments seems increasingly necessary. The goal of this thesis is to provide such an analysis.

## CHAPTER 2

### DETERMINING ENTRY AND EXIT THRESHOLDS

#### 2.1 Investment Valuation Methods

In the case of ethanol production, major capital investment decisions have to be made in a constantly changing environment. Risk and uncertainty exist in the dynamic nature of the ethanol market, which is influenced by factors such as policy reform, weather, crop disease, and commodity prices. Therefore, risk and uncertainty in markets as well as managerial abilities that can mitigate risk should be taken into account when making an investment decision.

##### 2.1.a The Net Present Value Approach

A rational manager would decide on projects based on both the returns and the risks associated with its undertaking. The traditional approach to valuing investment projects has been one based on NPV. Under this method, the present value of all future revenue streams is valued against the present value of the expected stream of expenditures necessary to carry out the project. If the NPV---the difference between the revenue stream and expenditure stream in present value terms---is greater than or equal to zero, the investment project is considered feasible. On the other hand, investment projects with an NPV below zero are infeasible. Formally, the NPV is determined as:

$$NPV = -CF_0 + \sum_{t=1}^{\infty} \frac{CF_t}{(1+r)^t}, \quad (2.1)$$

where  $CF_0$  is the initial investment cost,  $CF_t$  is the expected net cash flow from the investment in period  $t$ , and  $r$  is the discount rate.

Although there are further considerations such as the role of taxes, inflation, choice of discount rate, and the stochastic nature of investments, the NPV approach is a standard approach and widely used. However, as outlined by Dixit and Pindyck (1994) the NPV rule is constructed on flawed assumptions. Specifically, it assumes that:

1. the investment is reversible– the project can be undone and expenditures can be recovered if the business is performing below expectations; and
2. there is no option to delay the investment– if the manager does not invest now, the investment opportunity will be lost forever.

In most investment projects, these two assumptions will not hold, as many investments are irreversible and managers can often delay a project to a later time. These disadvantages of the NPV approach lead to new valuation methods that take into account irreversibility, uncertainty, and choice of timing of the investment.

### **2.1.b The Real Options Approach**

Options pricing theory was developed by Black and Scholes (1973), Merton (1973), and Cox and Ross (1976) as a tool to price financial securities based on the volatility of returns. Beginning with McDonald and Siegel (1985) options pricing theory was applied to tangible assets and “real” options theory was born. The approach is based on a key analogy with financial options; an irreversible investment opportunity is a financial option where the decision to enter is modeled as a call option and the decision to exit is modeled as a put option.

McDonald and Siegel (1986) were among the first to focus on valuing real options quantitatively. In their 1986 seminal paper they explain the options value method as one that compares the value of investing now with the present value of investing at any time in the future.

The real options approach encompasses a growing body of research emphasizing the fact that managers have *opportunities* to invest and thus their task is to decide on how to better seize those opportunities. Opportunities are *options*---rights but not obligations to take some action in the future (Dixit and Pindyck, 1994). Thus, opportunity to invest is seen like holding a call option. When a firm makes an irreversible investment, it exercises (kills) the option to invest in some future date. The NPV approach should be modified to include the value of holding an option. So, a firm should invest when the difference between the value of a unit of capital and the initial investment costs is greater than or equal to the value of keeping the investment option alive.

A vast literature has followed this line of thought, emphasizing the benefits from delaying an irreversible investment--the value of waiting. It can be summarized that the real options approach derives from the three common features of investment decisions (Dixit, 1992):

1. Investment entails a sunk cost-- cost of investment that cannot be completely recovered.
2. Market and economic uncertainty-- information arrives gradually.
3. Managers may have certain flexibility over the timing of the investment-- the investment opportunity will still be there tomorrow.

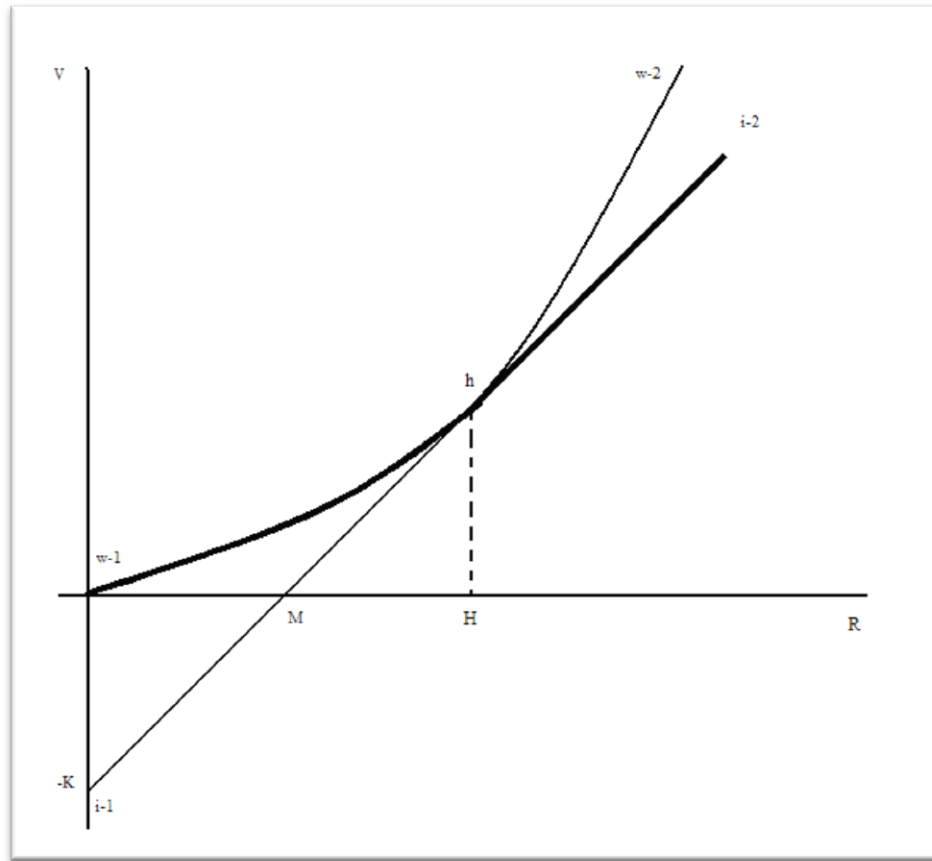
The ROA, therefore, builds on the traditional NPV approach and offers an enhanced foundation for risk management in investment projects facing irreversibility, uncertainty, and flexibility. The ROA is a valuable risk management tool as it offers managers the opportunity to manage the risk associated with an investment's future cash flow by revealing the optimal (dis)investing decision point given the volatility of the investment's net return (McClintock, 2009). Under this framework, the value of waiting is weighted against the opportunity cost of current profit over

the period of waiting. The ROA provides a trigger point at which conditions are satisfactory and the manager should take the optimal (dis)investment action.

To further illustrate timing of investment and the value of waiting in choosing an optimal policy Dixit's (1992) analysis is revisited, using figure 4. In the NPV framework, investment would be recommended when returns ( $R$ ) reach point  $M$  –the point at which the value of investing becomes positive, that is, where the line  $i_1i_2$  meets the horizontal axis. Clearly, the NPV approach fails to account for the stochastic nature of returns: there is no guarantee that returns will stay at level  $M$  for any period of time.

Let's now consider the real options approach, which allows one to model the value of waiting (curve  $w_1w_2$ ). The optimal policy is then to invest when the value of waiting equals the value of investing immediately –when curve  $w_1w_2$  becomes tangent to the return of investing immediately straight-line,  $i_1i_2$  (smooth pasting condition). At any point of  $R$  beyond  $H$ , the value of waiting stops having a valid explanation. The range from  $R=0$  to  $H$  is where the value of waiting is greater than the sacrifice of current profit. Therefore, under the ROA framework, investment is discouraged in this region until  $H$  is achieved. Consequently, the value of the opportunity to invest is given by the thick curve  $w_1h$  and the thick line  $hi_2$  together. Investing now has an opportunity cost: we lose the option to wait –represented as curve  $w_1w_2$ . A rational investor must add this forgone value to the cost of investment  $K$  to find the real cost of investing now. Immediate investment is then optimal at the point where the benefits of the project exceed its full cost –when current revenue  $R$  reaches trigger  $H$ .

Figure 4. Timing of Investment and the Value of Waiting



When uncertainty is high, there is increased value in waiting, in other words “setting a high trigger before taking action may avoid some very bad outcomes” (Dixit, 1992). On the other hand, if uncertainty is low, there is no or very little value in waiting. It is therefore for projects facing high uncertainty, as is the case with the establishment of an ethanol plant, where the ROA can yield significantly better results than the NPV approach. As uncertainty increases, the distance between  $M$  and  $H$  widens, yielding increasingly disparate investment triggers by the two methods. The ROA allows investors to manage risk by revealing the optimal waiting period, if any, before making an irreversible investment decision.

There is a rapidly growing body of literature analyzing a variety of real options applications, and natural resource investment projects have been the focus of numerous studies using the ROA. The availability of “traded resources or commodity prices, high volatilities and

long project durations” in this field means that the ROA yields higher option value estimates (Schwartz and Trigeorgis, 2001). In their 1985 papers, Brennan and Schwartz valued the options to abandon a mine using the convenience yield derived from futures and spot prices of the commodity. Paddock, Siegel, and Smith (1987) valued options in the case of offshore petroleum leases. The findings of Myers (1987) suggest that option pricing is the most suitable valuation method for investments with significant options. Bjerk Sund and Ekern (1990) estimate the value of a Norwegian oilfield with options to delay or abandon.

The field of agricultural economics has embraced real options methodology; it has been used to analyze a multitude of investment decisions in agriculture. Purvis et al. (1995) adapt the Dixit-Pindyck real options framework to study dairy producer’s investment behavior. They determine that irreversibility and uncertainty play a vital role in dairy producer’s inclination to adopt new technology. Ekboir (1997) analyzes the dynamics of investment by an individual farmer when “decisions are partially irreversible, technical change is embedded and capital is indivisible”. Winter Nelson and Amegbeto (1998) empirically explore whether commodity market liberalization could change option values enough to influence terrace adoption in Kenya. Price and Wetzstein (1999) calculate optimal entry and exit thresholds for Georgia commercial peach production when price and yield follow a stochastic process. Isik et al. (2001) develop an option-value model to analyze the impacts of output price uncertainty, high sunk costs of adoption and site-specific conditions on the optimal timing of adoption of two interrelated agricultural sit-specific technologies, soil testing and variable rate technology. They find that an ROA model provides a better explanation for technology adoption behavior observed in the field than models based on the NPV rule. Pederson and Zou (2009) use real options to evaluate ethanol plant expansion decisions. They demonstrate that ROA and simulation can be used to

evaluate ethanol plant investments by using available historical industry and market price data. Most recently and very relevant to this thesis, Luo (2009) evaluates optimal entry and exit decisions using a real options approach with two stochastic variables.

The value of real options approach consists in its ability to incorporate managerial flexibility into firm's capital budgeting decisions. The timing of an investment, market uncertainty, and irreversibility of some decisions are critical investment conditions that the NPV approach fails to account for. In the agricultural capital investment sector, where firms face a highly volatile environment and high sunk investments, the NPV approach may lead firms to make incorrect investment decisions. Therefore, the real options approach may provide increasingly valuable risk-management insights to aid in the investment decisions of the agricultural sector.

## **2.2 Theoretical Background**

This section introduces the reader the mathematical tools needed to study investment decisions under the real options framework using a continuous-time approach and draws heavily from chapters 3 and 7 of Dixit and Pindyck (1994).

### **2.2.a Stochastic Processes**

A stochastic process is “a variable that evolves over time in a way that is at least in part random”. Examples of stochastic processes include the prices of stocks and commodities, interest rates, and the temperature in a given city.

We can categorize stochastic processes as stationary or non-stationary processes. A stationary process is one in which the “statistical properties of the variable are constant over long periods of time”. A non-stationary process, on the other hand, is one in which the expected value of the variable can grow without bound.

Further, discrete-time processes are those variables whose values change only at certain discrete points in time. Conversely, a continuous-time stochastic process is one that varies continuously through time, such as temperature in a city. A simple example of a stochastic process is *the discrete-time discrete-state random walk*. In such a process,  $x_t$  is a random variable that begins at a known value  $x_0$ , and at times  $t = 1, 2, 3, \dots$ , makes independent jumps of size 1 either up or down each with probability  $\frac{1}{2}$ . Thus,  $x_t$  can be mathematically represented with the following equation:

$$x_t = x_{t-1} + \varepsilon_t, \quad (2.2)$$

where  $\varepsilon_t$  is a random variable with probability distribution

$$\text{prob}(\varepsilon_t = 1) = \text{prob}(\varepsilon_t = -1) = \frac{1}{2} \quad (t = 1, 2, 3, \dots).$$

The probability distribution for  $x_t$  comes from the binomial distribution. For  $t$  steps, the probability that there are  $n$  downward jumps and  $t-n$  upward jumps is

$$\binom{t}{n} 2^{-t}$$

Subsequently, the probability that  $x_t$  takes on the value  $t-2n$  at time  $t$  is

$$\text{prob}(x_t = t - 2n) = \binom{t}{n} 2^{-t} \quad (2.3)$$

It is worth noting that the variance of  $x_t$  as well as the range of values which it can take increases with  $t$ . For this reason  $x_t$  is a nonstationary process.

In order to make this process a bit more general, we can change the probabilities for an upward or downward jump. Let  $p$  be the probability of an upward jump and  $q = (1 - p)$  be the probability of a downward jump, with  $p > q$ . In this process, we observe that at time  $= 0$ , the expected value of  $x_t$  for  $t > 0$  is greater than zero and increasing with  $t$ ; it is therefore called a

*random walk with drift*. For further generalization we could let the size of each jump at time  $t$  be a continuous random variable. For instance, let the size of each jump be normally distributed with mean zero and standard deviation  $\sigma$ . In this case  $x_t$  is a *discrete-time continuous-state stochastic process*.

The above processes are called *Markov processes*. They satisfy the Markov property that the probability distribution for  $x_{t+1}$  depends only on  $x_t$ , and not additionally on what happened before time  $t$ . This property is relevant as it can make the analysis of a stochastic process much more straightforward.

## 2.2.b Brownian Motion

A Brownian motion, or a Wiener process, is a continuous-time stochastic process with three key properties:

1. It is a *Markov process*. As implied by the explanation above, the current value of the process is the only requirement to make a best forecast of its future value.
2. It has *independent increments*. The probability distribution for the change in the process over any time interval is independent of any other time interval. This property allows us to think of a Wiener process as a continuous-time version of a random walk.
3. Changes in the process over any finite interval of time are *normally distributed*, with a variance that increases linearly with the time interval.

More formally, if  $z(t)$  is a Wiener process, then any change in  $z$ ,  $\Delta z$ , corresponding to a time interval  $\Delta t$ , satisfies the following conditions:

- a. The relationship between  $\Delta t$  and  $\Delta z$  is given by

$$\Delta z = \varepsilon_t \sqrt{\Delta t},$$

where  $\varepsilon_t$  is a normally distributed random variable with mean of zero and standard deviation of 1.

- b. The random variable  $\varepsilon_t$  is serially uncorrelated, specifically,  $E[\varepsilon_t \varepsilon_s] = 0$  for  $t \neq s$ . Hence, the values for any two different  $t$  intervals are independent.

If we break a finite interval of time  $T$  into  $n$  units of length  $\Delta t$  each, with  $n = T / \Delta t$ , then the change in  $z$  over this interval is given by

$$z(s + T) - z(s) = \sum_{i=1}^n \varepsilon_i \sqrt{\Delta t} \quad (2.4)$$

Because the  $\varepsilon_i$ 's are independent of each other, it is possible to apply the Central Limit Theorem to their sum. Therefore, the change  $z(s + T) - z(s)$  is normally distributed with mean zero and variance  $n\Delta t = T$ . This means that the variance of the change in a Wiener process grows linearly with the time horizon –the Wiener process is nonstationary. Now, by letting  $\Delta t$  be infinitesimally small, the increment of a Wiener process in continuous time,  $dz$ , can be represented as

$$dz = \varepsilon_t \sqrt{dt}, \quad (2.5)$$

where  $E(dz) = 0$ , and  $\text{Var}[dz] = E[(dz)^2] = dt$ .

The simplest generalization of equation (2.5) is the *Brownian motion with drift*:

$$dx = \alpha dt + \sigma dz, \quad (2.6)$$

where  $dz$  is the increment of a Wiener process, which we already defined;  $\alpha$  is the drift parameter, and  $\sigma$  is the variance parameter. Here, over any time interval  $\Delta t$ , the change in  $x$ ,  $\Delta x$ , is normally distributed with expected value  $E(\Delta x) = \alpha \Delta t$ , and variance  $\text{Var}[\Delta x] = \sigma^2 \Delta t$ .

The Wiener process can serve as a key element to model a variety of stochastic variables. The following equation is a generalization of the simple Brownian motion with drift and is called an Ito process:

$$dx = a(x,t) dt + b(x,t) dz, \quad (2.7)$$

where  $dz$  is the increment of a Wiener process, and  $a(x, t)$ , and  $b(x, t)$  are known (nonrandom) functions. The drift and variance coefficients are now functions of the current state and time.

An important special case of equation (2.7) is the geometric Brownian motion (GBM) with drift. In this case,  $a(x,t) = \alpha x$ , and  $b(x,t) = \sigma x$ , where  $\alpha$  and  $\sigma$  are constants. Therefore, equation (2.7) can be written as:

$$dx = \alpha x dt + \sigma x dz. \quad (2.8)$$

Dixit and Pindyck (1994) show, through the use of Ito's lemma, that if  $x(t)$  is given by equation (2.8), then  $F(x) = \log x$  is the following simple Brownian motion with drift:

$$dF = \left( \alpha - \frac{1}{2} \sigma^2 \right) dt + \sigma dz, \quad (2.9)$$

so that over a finite time interval  $t$ , the change in the logarithm of  $x$  is normally distributed with mean  $(\alpha - \frac{1}{2} \sigma^2)t$  and variance  $\sigma^2 t$ .

## 2.3 Entry-Exit Model

This section covers the theory behind the one variable entry-exit model under the Real Options Approach.

### 2.3.a The Investment Problem

We examine the investment decision of a firm that is considering the following investment opportunity: at any time  $t$ , the firm can pay  $I$  to build the project (startup costs). The cost of capital is  $\delta$ . Expected future net cash flows conditional on embarking on the project have a present value  $P$  – in this case, it denotes the ethanol gross margin, which is computed as the difference between the price of ethanol per gallon and the price of corn necessary to produce one gallon of ethanol. If entry is made, the firm acquires a project that produces a fixed amount of product (ethanol) each year, which is normalized to unity. Variable operating costs,  $C$ , are known

and constant. Once in operation, the firm has the option to abandon the project at a cost of  $E$ . Additionally, the firm takes  $P$  as given ( $P$  is a stochastic process), and this “price” is assumed to follow a geometric Brownian motion,

$$dP = \alpha P dt + \sigma P dz. \quad (2.10)$$

In terms of the ROA, the live project can be seen as a composite asset, part of which is an option to abandon. If the firm exercises this option, the project goes back to the inactive state. Namely, the firm acquires another asset –the option to invest. When the firm subsequently exercises this option, they have a live project once more. As a result, “the values of a live firm and an idle firm are interlinked and must be determined simultaneously” (Dixit and Pindyck, 1994).

A rational investor will enter when market conditions become sufficiently favorable, and an active firm will exit when conditions become sufficiently poor. The optimal strategy for entry and exit is determined in the form of two threshold prices,  $P_H$  and  $P_L$ , respectively, with  $P_H > P_L$ . The optimal strategy for an idle firm facing  $P$  below  $P_H$  is to remain idle, and to invest as soon as  $P$  reaches the threshold level  $P_H$ . Conversely, the optimal strategy for an active firm is to remain active as long as  $P$  is greater than  $P_L$  but exit as soon as  $P$  falls to  $P_L$ . The problem is then to find out these threshold prices.

## **2.3.b Valuing Entry and Exit Options and Solving Threshold Margins**

### **2.3.b.1 Real Options Margins**

Given the assumptions above, the investment problem is then to decide when an idle project should be initiated and when an active project should be terminated as a response to the stochastic margin  $P$ , given the constant parameters  $I$ ,  $E$ ,  $\alpha$ ,  $\sigma$ , and  $\delta$ .

In the ROA context, the value of the firm is now a function of the exogenous state variable  $P$ , and of the discrete variable that indicates whether the firm is idle (subscript 0) or

active (subscript 1). Let  $V_0(P)$  represent the value of an idle firm, or the option to invest, and  $V_I(P)$  represent the value of an active firm.  $V_I(P)$  comprises of two parts, the rights to the profit from the venture, and the option to exit if  $P$  falls below  $P_L$ .

An idle project does not generate revenue and does not incur any costs. However, if and when prices become favorable enough, it might become an active project and start generating revenue. The value of the idle project is given by  $V_0(P)$  or  $V_0$ . This represents also the value of the option to invest. Once active, the plant generates a stochastic net return of  $\pi=P-C$  in each period, while still having the option of shutting down. The value of the active project is given by  $V_I(P)$  or  $V_I$ .

The Bellman equations are then given by,

$$\delta V_0(P)dt = E[dV_0] \quad (2.11)$$

$$\delta V_1(P)dt = E[V_1] + (P - C)dt. \quad (2.12)$$

The idle project equation tells us that normal return from an idle project should be equal to expected capital gain from undertaking the project. The active project equation shows that normal return from an active project should be equal to expected capital gain plus net revenue from the project.

Applying Ito's lemma to  $dV_0$  yields

$$dV_0 = \frac{\partial V_0}{\partial P} dP + \frac{1}{2} \frac{\partial^2 V_0}{\partial P^2} (dP)^2 \quad (2.13)$$

$$dV_0 = V'_0 dP + \frac{1}{2} V''_0 (dP)^2. \quad (2.14)$$

We now substitute  $dP = \alpha P dt + \sigma P dz$  and we obtain

$$dV_0 = V'_0 \alpha P dt + V'_0 \sigma P dz + \frac{1}{2} V''_0 \alpha^2 P^2 (dt)^2 + \frac{1}{2} V''_0 \sigma^2 P^2 (dz)^2 + V''_0 \alpha \sigma P^2 dt dz. \quad (2.15)$$

Therefore,

$$E[dV_0] = \alpha \cdot P \cdot V_0' + \frac{1}{2} \sigma^2 \cdot P^2 \cdot V_0'' . \quad (2.16)$$

Substituting the above into equation (2.11) we obtain,

$$\delta V_0 = \alpha \cdot P \cdot V_0' + \frac{1}{2} \sigma^2 \cdot P^2 \cdot V_0'' . \quad (2.17)$$

Rearranging,

$$\frac{1}{2} \sigma^2 \cdot P^2 \cdot V_0'' + \alpha \cdot P \cdot V_0' - \delta V_0 = 0 . \quad (2.18)$$

In the same way, we apply Ito's lemma to  $dV_1$ :

$$dV_1 = V_1' dP + \frac{1}{2} V_1'' (dP)^2 \quad (2.19)$$

$$E[dV_1] = \alpha \cdot P \cdot V_1' + \frac{1}{2} \sigma^2 \cdot P^2 \cdot V_1'' . \quad (2.20)$$

Substituting equation (2.12) and rearranging we obtain,

$$\delta V_1 = \alpha \cdot P \cdot V_1' + \frac{1}{2} \sigma^2 \cdot P^2 \cdot V_1'' + P - C \quad (2.21)$$

$$\frac{1}{2} \sigma^2 \cdot P^2 \cdot V_1'' + \alpha \cdot P \cdot V_1' - \delta V_1 + P - C = 0 . \quad (2.22)$$

The general solution to equation (2.18) can be denoted as

$$V_0(P) = A_1 P^{\beta_1} + A_2 P^{\beta_2} , \quad (2.23)$$

where  $A_1$  and  $A_2$  are constants yet to be determined and  $\beta_1$  and  $\beta_2$  are the roots of the quadratic

equation  $\frac{1}{2} \sigma^2 \beta (\beta - 1) + \alpha \beta - \delta = 0$ :

$$\beta_1 = \left( \frac{1}{2} - \frac{\alpha}{\sigma^2} \right) + \sqrt{\left( \frac{1}{2} - \frac{\alpha}{\sigma^2} \right)^2 + \frac{2\delta}{\sigma^2}} > 1 \quad (2.24)$$

$$\beta_2 = \left( \frac{1}{2} - \frac{\alpha}{\sigma^2} \right) - \sqrt{\left( \frac{1}{2} - \frac{\alpha}{\sigma^2} \right)^2 + \frac{2\delta}{\sigma^2}} < 0 , \quad (2.25)$$

with  $\delta > \alpha$ .

The option to invest becomes nearly worthless as  $P$  approaches 0. Therefore, the coefficient  $A_2$  corresponding to the negative root  $\beta_2$  ought to be zero. In this case, the solution over the  $P$  interval  $(0, P_H)$  –the idle firm, becomes

$$V_0(P) = A_1 P^{\beta_1}. \quad (2.26)$$

Next we consider the value of an active firm, equation (2.22). The estimation is analogous to the above, except the active project pays a net cash flow  $(P - C)$ . Hence, the general solution to equation (2.22) is given by

$$V_1(P) = B_1 P^{\beta_1} + B_2 P^{\beta_2} + \frac{P}{\delta - \alpha} - \frac{C}{\delta}. \quad (2.27)$$

The last two terms in the above equation can be interpreted as the value of the active project when the firm must keep it operational forever regardless of any losses. The first two terms can be interpreted as the value of the option to abandon. As  $P$  goes to  $\infty$ , the likelihood of abandonment becomes very small, thus the value of the exit option should go to zero as  $P$  becomes extremely large. For this reason, the coefficient  $B_1$  corresponding to the positive root  $\beta_1$  should be zero. Then the solution over the  $P$  interval  $(P_L, \infty)$  becomes

$$V_1(P) = B_2 P^{\beta_2} + \frac{P}{\delta - \alpha} - \frac{C}{\delta}. \quad (2.28)$$

If the entry threshold  $P_H$  is reached, the investing firm pays the lump-sum cost  $I$  to exercise its investment option, relinquishing the rights to the asset of value  $V_0(P_H)$  to get the active project with value  $V_1(P_H)$ . In this case, the conditions of value matching and smooth pasting are

$$V_0(P_H) = V_1(P_H) - I, \quad V_0'(P_H) = V_1'(P_H).$$

Also, at the exit threshold  $P_L$ , the value matching and smooth pasting conditions are

$$V_1(P_L) = V_0(P_L) - E, \quad V_1'(P_L) = V_0'(P_L).$$

Substituting equations (2.26) and (2.28) into the value matching and smooth pasting conditions we obtain the following four equations:

$$-A_1 P_H^{\beta_1} + B_2 P_H^{\beta_2} + \frac{P_H}{\delta - \alpha} - \frac{C}{\delta} - I = 0 \quad (2.29)$$

$$-\beta_1 A_1 P_H^{\beta_1 - 1} + \beta_2 B_2 P_H^{\beta_2 - 1} + \frac{1}{\delta - \alpha} = 0 \quad (2.30)$$

$$-A_1 P_L^{\beta_1} + B_2 P_L^{\beta_2} + \frac{P_L}{\delta - \alpha} - \frac{C}{\delta} + E = 0 \quad (2.31)$$

$$-\beta_1 A_1 P_L^{\beta_1 - 1} + \beta_2 B_2 P_L^{\beta_2 - 1} + \frac{1}{\delta - \alpha} = 0 \quad (2.32)$$

Using numerical methods, this four unknown, four-equation system can be solved for the entry/exit thresholds  $P_H$  and  $P_L$  and the coefficients  $A_1$  and  $B_2$ .

### 2.3.b.2 Net Present Value Margins

To derive the NPV entry and exit thresholds we define net returns  $\pi$  for year  $i$  as  $\pi_i = P(1 + \alpha)^i - C$ , where  $P$  is gross margin at year 0,  $\alpha$  is the drift rate of the gross margin and  $C$  are the operating costs. Therefore, the discounted net return for year  $i$  is given by

$$P \left( \frac{1 + \alpha}{1 + \delta} \right)^i - \frac{C}{(1 + \delta)^i}. \quad (2.33)$$

The present value of the net return summed over an infinite time horizon is then,

$$\sum_{i=1}^{\infty} \left( P \left( \frac{1 + \alpha}{1 + \delta} \right)^i - \frac{C}{(1 + \delta)^i} \right). \quad (2.34)$$

From the above equation, the present value of gross returns is found as

$$PV(R) = \frac{P(1 + \alpha)}{\delta - \alpha}, \quad (2.35)$$

and the present value of costs is given by

$$PV(c) = \frac{C}{\delta}. \quad (2.36)$$

As a result, the present value of the net return is

$$\frac{P(1 + \alpha)}{\delta - \alpha} - \frac{C}{\delta}. \quad (2.37)$$

According to the NPV criteria, in order for an investment to be carried out, the present value of the net return should exceed the initial investment costs,  $I$ . Therefore, the investment decision under the NPV approach is given by

$$\frac{P(1 + \alpha)}{\delta - \alpha} - \frac{C}{\delta} - I > 0. \quad (2.38)$$

Entry threshold is obtained by solving the above equation for  $P$ :

$$P_{NPV}^{Entry} = \left( \frac{C}{\delta} + I \right) \left( \frac{\delta - \alpha}{1 + \alpha} \right). \quad (2.39)$$

Furthermore, the exit criterion under the NPV approach states that an investment must be abandoned if the present value of the net return of the ethanol plant is less than the plant's scrap value,  $E$ . Thus, the exit decision under the NPV approach is

$$\frac{P(1 + \alpha)}{\delta - \alpha} - \frac{C}{\delta} < -E. \quad (2.40)$$

The exit threshold is then given by

$$P_{NPV}^{Exit} = \left( \frac{C}{\delta} - E \right) \left( \frac{\delta - \alpha}{1 + \alpha} \right) \quad (2.41)$$

## CHAPTER 3

### DATA AND PARAMETER ESTIMATES

This chapter details the data and parameters used in the estimation process. First, we review the price data used to obtain the stochastic price margin  $P$ . Then, we examine capital cost estimates for the establishment of the ethanol plants. Lastly, we look into the cost of operating the ethanol plants.

#### 3.1 Price Data

Price of ethanol fluctuates over time. From a producer's perspective, this implies that the price of its output changes randomly over time, and it exhibits uncertainty. The stochastic behavior of ethanol price then also makes the firm's expected future revenues stochastic. Corn is the main input for ethanol production and like ethanol prices, corn prices also exhibit stochastic behavior---corn prices are volatile and move randomly. Thus, a manager is required to make an investment decision when both the revenues (ethanol price) and costs (corn price) are stochastic. The data on prices of ethanol ( $P_E$ ) and corn ( $P_C$ ) are obtained from the HART's Ethanol and Biofuels News database. The data consist of weekly prices from March 30, 1989 to February 27, 2009. The United States Department of Energy geographically aggregates the 50 States and the District of Columbia into five Petroleum Administration for Defense Districts (PADDs). The weekly series of ethanol prices is computed as the U.S. average of the price of ethanol across all five PADD's over the previously mentioned time period. Moreover, the weekly series of corn prices is computed as the average of cash corn price in Kansas City and Chicago net of DDG

revenue. Therefore, they represent the dry mill net corn cost in dollars per gallon of ethanol on a weekly basis.

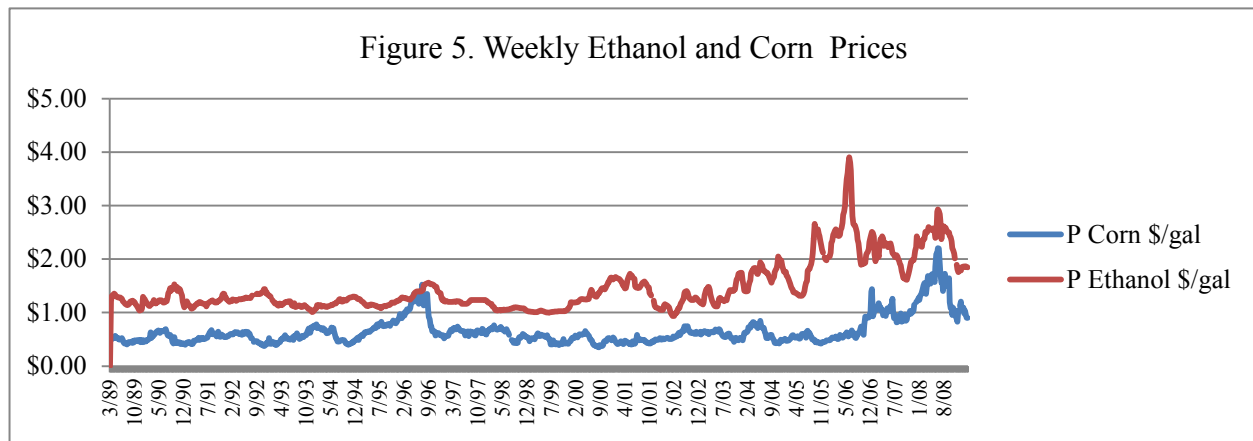


Figure 5 shows weekly ethanol and corn prices from March 1989 to February 2009. Notice that the price of corn time series is in dollars per gallon; this represents the price of corn needed to produce one gallon of ethanol. Also notice that both series generally move in the same direction and both exhibit a general upward trend. Additionally, volatility has increased over time; both time series show more dramatic peaks and troughs in the latter years.

In order to keep the entry-exit model simple, stochastic prices of ethanol and corn are used to create a single stochastic variable, called gross margin  $P$ . This key variable is obtained by subtracting the net corn cost from the gross revenue obtained from ethanol sales, its price. Specifically, the gross margin is  $P = P_E - P_C$ .

### 3.2 Technology and Costs of Production for Conventional Ethanol Plants

A conventional dry grind ethanol plant uses the entire corn kernel as feedstock for the production of ethanol. During this process, the whole corn kernel is broken up into small pieces, and then fermented by the addition of various enzymes and yeasts. The process ultimately produces ethanol and dried distillers grains and solubles (DDGS), a feed product.

The following cost data are obtained from the 2007 study “The Economics of Ethanol Production in Georgia” published by the Center for Agribusiness and Economic Development at The University of Georgia. The cost estimates were obtained from Frazier, Barnes and Associates. Table 2 is a summary of the estimated capital costs expected from building and starting up the 50 and 100 million gallon ethanol plants. Capital costs include all costs associated with the construction of the ethanol plant- the actual plant, the railroad system, site preparation, engineering and permitting costs. Capital costs also include costs that are not construction related such as the land, start-up inventories, and working capital. We arrive at total capital costs of \$1.85/gallon and \$1.71/gallon for the 50 and 100 million gallon plants, respectively. All capital costs are treated as sunk costs,  $I$ , in the investment analysis.

| <b>Table 2. Capital Cost Estimates for Selected Size Conventional Ethanol Plants</b> |                     |                      |
|--------------------------------------------------------------------------------------|---------------------|----------------------|
|                                                                                      | <b>50mm Gal</b>     | <b>100mm Gal</b>     |
| Ethanol Plant                                                                        | \$70,000,000        | \$140,000,000        |
| Railroad System                                                                      | 2,800,000           | \$2,800,000          |
| Site Prep/Underground/Fire                                                           | \$7,000,000         | \$7,000,000          |
| Construction Contingency (5%)                                                        | \$4,137,400         | \$7,694,900          |
| Engineering and Permitting                                                           | \$328,000           | \$328,000            |
| Phase I and II Environmental                                                         | \$10,000            | \$10,000             |
| Electrical and Utilities                                                             | \$2,000,000         | \$3,000,000          |
| Admin Building                                                                       | \$300,000           | \$300,000            |
| Land                                                                                 | \$300,000           | \$450,000            |
| Site Survey                                                                          | \$10,000            | \$10,000             |
| Feedstock/Working/Start-up                                                           | \$5,500,000         | \$9,000,000          |
| <b>Total Capital Cost</b>                                                            | <b>\$92,385,400</b> | <b>\$170,592,900</b> |
| <b>Total Capital Cost per Gallon</b>                                                 | <b>\$1.85</b>       | <b>\$1.71</b>        |

In addition to establishment costs, operating costs, denoted by  $C$ , are also obtained from the same publication for the selected size ethanol plants. Processing costs, which include chemical and utility costs, total around \$22.3 million and \$44.60 million for the 50 and 100 million gallon plants, respectively. Chemical costs include chemicals, raw materials, and non-corn feedstock cost---denaturants, enzymes, and yeasts. Utility costs include fresh water source, natural gas, electricity, wastewater, stormwater and sanitary sewage.

Labor at the assumed wage rate is also included in the production costs. Additionally, production costs include depreciation of the plants and the machinery which are used in the

ethanol production process. Normal business operating expenses such as repairs and maintenance, insurance, marketing and freight, and other expenses are also included. Total operating costs per gallon  $C$  are \$0.77 and \$0.75 for the 50 and 100 million gallon plants, respectively. The relevant operating costs are displayed in table 3.

| <b>Table 3. Economic Costs of Selected Size Ethanol Plants – Million Dollars</b> |                 |                  |
|----------------------------------------------------------------------------------|-----------------|------------------|
| <b>Production Costs</b>                                                          | <b>50mm Gal</b> | <b>100mm Gal</b> |
| Processing Costs                                                                 | \$22.30         | \$44.60          |
| Labor                                                                            | \$1.50          | \$1.80           |
| Repairs and Maintenance                                                          | \$1.00          | \$2.00           |
| Insurance                                                                        | \$0.40          | \$0.80           |
| Marketing and Freight                                                            | \$3.50          | \$7.00           |
| Other; Selling, General & Administrative Expenses                                | \$4.00          | \$8.20           |
| Depreciation                                                                     | \$5.80          | \$10.70          |
| <b>Total Operating Cost</b>                                                      | <b>\$38.50</b>  | <b>\$75.10</b>   |
| <b>Total Operating Cost per Gallon</b>                                           | <b>\$0.77</b>   | <b>\$0.75</b>    |

Exit costs depend on the liquidation value of the assets. Unfortunately, no data specific to the residual value of an ethanol plant are available in the literature. Therefore, the sunk exit costs are defined as 10% of establishment costs ( $E = -0.10I$ ) in the benchmark model and a sensitivity analysis is conducted later on.

The cost of capital,  $\delta$ , is yet another major factor influencing a firm's capital investment decisions. It represents the minimum required rate of return on investment funds. It can also be thought of as the rate of return that an investor would earn from a different investment with

similar risk. For this analysis, an annual 15% cost of capital is assumed. Additionally, sensitivity analysis with respect to the choice of cost of capital is conducted.

### 3.3 Estimation of Geometric Brownian Motion Parameters

If the stochastic variable  $P = P_E - P_C$  follows a geometric Brownian motion

$$dP = \alpha P dt + \sigma P dz, \quad (3.1)$$

then  $\ln P$  follows a Brownian motion with drift parameter  $\alpha - \frac{1}{2}\sigma^2$  and volatility  $\sigma$ . More specifically,

$$\begin{aligned} \mu &= \alpha - \frac{1}{2} \sigma^2 \\ \alpha &= \mu + \frac{1}{2} \sigma^2 \end{aligned} \quad (3.2)$$

The weekly gross margin series  $P$  are averaged over each year to construct a yearly series. The resulting series were nonstationary. To remedy this problem the drift and volatility parameters are computed as the sample mean and standard deviation of the first difference of the natural log of the annual gross margin series,  $\Delta \ln P_t = \ln P_t - \ln P_{t-1}$ . The drift parameter ( $\mu$ ) of the  $\ln P$  variable is found as 0.007 and volatility parameter as 0.31. Thus, the drift and volatility parameters of the variable  $P$  are  $\alpha = 0.07 + \frac{1}{2}(0.31)^2 = 0.055$  and  $\sigma = 0.31$ . Table 4 lists all the cost variables and stochastic parameters used in the empirical analysis.

**Table 4. Estimated Parameters**

| Parameter | Value    |           | Description                |
|-----------|----------|-----------|----------------------------|
|           | 50mm Gal | 100mm Gal |                            |
| $I$       | 185      | 171       | Entry cost in ¢/gallon     |
| $E$       | $0.10I$  | $0.10I$   | Exit cost in ¢/gallon      |
| $C$       | 77       | 75        | Operating cost in ¢/gallon |
| $\delta$  | 0.15     | 0.15      | Cost of capital            |
| $\alpha$  | 0.055    | 0.055     | Annual drift rate          |
| $\sigma$  | 0.31     | 0.31      | Annual rate of volatility  |

## CHAPTER 4

### ENTRY AND EXIT THRESHOLD MARGINS FOR ETHANOL PLANTS

#### 4.1 Benchmark Results

Entry and exit threshold margins are computed under both the real options and net present value approaches using the benchmark values of the parameters given in table 4. Table 5 summarizes these results for both plant sizes. Under the ROA, we obtain a trigger entry price  $P_H$  of 154.81 ¢/gallon for the 50 million gallon plant and 148.36 ¢/gallon for the 100 million gallon plant. Trigger exit price  $P_L$  is 43.48 ¢/gallon for the 50 million gallon plant and 42.62 ¢/gallon for the 100 million gallon plant.

Not surprisingly, the ROA estimates differ from those of the NPV approach. The trigger gross margin estimates for entry ( $P_H$ ) are much higher under the ROA for both plant sizes. Under the NPV approach, entry trigger gross margins are found as 62.82¢/gallon and 60.36¢/gallon for the 50mm and 100mm gallon plants, respectively. Conversely, the trigger gross margin for exit ( $P_L$ ) are very close across the two approaches and plant sizes, with the NPV approach yielding slightly higher estimates than the ROA. In practice, these estimates suggest that under the ROA, a firm will wait to make an ethanol plant investment until market conditions make it possible to obtain a higher gross margin. The results also suggest that once in operation, a firm's exit trigger gross margin is slightly lower under the ROA. The gap between entry and exit price thresholds under the ROA is 111.43 ¢/gallon while the gap between entry and exit price thresholds under the NPV approach is only 18.31¢/gall. These results are consistent with Dixit and Pindyck's argument: "the optimal thresholds with rational expectations (ROA) are spread farther apart than

the Marshallian ones with static expectations” (NPV). As the uncertainty over the gross margin is taken into account by investors, they become more hesitant to invest; and if the ethanol plant is already active, the investors are more hesitant to exit the market. Put differently, uncertainties over future market conditions enlarge the firm’s “status quo” zone.

| <b>Table 5. Threshold Gross Margins (¢/gallon)</b> |            |       |         |            |       |         |
|----------------------------------------------------|------------|-------|---------|------------|-------|---------|
|                                                    | 50 mm gall |       |         | 100mm gall |       |         |
|                                                    | ROA        | NPV   | NPV-ROA | ROA        | NPV   | NPV-ROA |
| $P_H$                                              | 154.81     | 62.82 | -91.99  | 148.36     | 60.36 | -88.00  |
| $P_L$                                              | 43.38      | 44.51 | 1.13    | 42.64      | 43.44 | 0.79    |
| Gap                                                | 111.42     | 18.31 | -93.12  | 105.72     | 16.92 | -88.79  |

## 4.2 Sensitivity Analyses

### 4.2.a Sensitivity to Drift and Volatility Parameters

It is useful to examine how the thresholds behave when the drift ( $\alpha$ ) and volatility ( $\sigma$ ) parameters are changed. Table 6 presents entry and exit trigger margins computed with different values of  $\alpha$  under both ROA and NPV approaches.

| <b>Table 6. Sensitivity to the Drift Parameter</b> |          |             |       |        |       |       |       |         |       |
|----------------------------------------------------|----------|-------------|-------|--------|-------|-------|-------|---------|-------|
|                                                    |          | 50 mm gall  |       |        |       |       |       |         |       |
|                                                    |          | ROA         |       |        | NPV   |       |       | NPV—ROA |       |
|                                                    | $\alpha$ | $P_H$       | $P_L$ | Gap    | $P_H$ | $P_L$ | Gap   | $P_H$   | $P_L$ |
|                                                    | 0.035    | 159.28      | 45.22 | 114.06 | 77.59 | 54.98 | 22.61 | -81.68  | 9.76  |
| Benchmark                                          | 0.055    | 154.81      | 43.38 | 111.42 | 62.82 | 44.51 | 18.31 | -91.99  | 1.13  |
|                                                    | 0.075    | 150.59      | 41.53 | 109.06 | 48.72 | 34.52 | 14.20 | -101.87 | -7.01 |
|                                                    |          | 100 mm gall |       |        |       |       |       |         |       |
|                                                    | 0.035    | 152.56      | 44.39 | 108.17 | 74.49 | 53.61 | 20.88 | -78.07  | 9.22  |
| Benchmark                                          | 0.55     | 148.36      | 42.64 | 105.72 | 60.36 | 43.44 | 16.92 | -88     | 0.79  |
|                                                    | 0.075    | 144.39      | 40.87 | 103.52 | 46.75 | 33.65 | 13.11 | -97.64  | -7.22 |

Observe that under both approaches, as the drift parameter  $\alpha$  gets larger, the inaction gap gets smaller under both the ROA and the NPV approaches. A higher drift rate means that, all else held equal, the price margin is expected to be higher in the future. For the 50 million gallon plant, we observe that when  $\alpha=0.035$ , the ROA trigger entry price is 159.28 ¢/gallon; and when  $\alpha=0.075$ , the ROA trigger entry price is 150.59¢/gall. Since the price margin is expected to be higher in the future, the firm's minimum margin to invest now ( $P_H$ ) is lower. The column labeled "Gap" in table three shows values for the inaction gap; notice that the inaction gap is much larger under ROA than under the NPV approach and that the gap gets larger as the drift parameter grows. A firm using the NPV approach is much more reactive to changes in the drift rate, investing sooner when the drift is high and also exiting more readily when drift is low.

Table 7 presents entry and exit trigger margins computed with different values of the volatility parameter  $\sigma$  under both ROA and NPV approaches.

| <b>Table 7. Sensitivity to the Volatility Parameter</b> |          |             |       |        |       |       |       |         |       |
|---------------------------------------------------------|----------|-------------|-------|--------|-------|-------|-------|---------|-------|
|                                                         |          | 50 mm gall  |       |        |       |       |       |         |       |
|                                                         |          | ROA         |       |        | NPV   |       |       | NPV-ROA |       |
|                                                         | $\sigma$ | $P_H$       | $P_L$ | Gap    | $P_H$ | $P_L$ | Gap   | $P_H$   | $P_L$ |
|                                                         | 0.21     | 133.71      | 46.98 | 86.72  | 62.82 | 44.51 | 18.31 | -70.89  | -2.47 |
| Benchmark                                               | 0.31     | 154.81      | 43.38 | 111.42 | 62.82 | 44.51 | 18.31 | -91.99  | 1.13  |
|                                                         | 0.41     | 176.86      | 40.26 | 136.60 | 62.82 | 44.51 | 18.31 | -114.04 | 4.25  |
|                                                         |          | 100 mm gall |       |        |       |       |       |         |       |
|                                                         | 0.21     | 128.35      | 46.14 | 82.21  | 60.36 | 43.44 | 16.92 | -67.99  | -2.7  |
| Benckmark                                               | 0.31     | 148.36      | 42.64 | 105.72 | 60.36 | 43.44 | 16.92 | -88     | 0.79  |
|                                                         | 0.41     | 169.17      | 39.6  | 129.57 | 60.36 | 43.44 | 16.92 | -108.81 | 3.84  |

Observe that greater gross margin volatility causes the inaction gap to expand. In other words, as uncertainty over gross margin increases, firms become increasingly reluctant to make investment/disinvestment decisions. An increase in volatility from  $\sigma=0.21$  to  $\sigma=0.41$  causes the inaction gap to increase from 86.72 ¢/gallon to 136.60 ¢/gallon in the 50mm gallon plant and from 82.21 ¢/gallon to 129.57 ¢/gallon in the 100mm gallon plant. As the volatility of gross margin increases, there is increased value in waiting to invest when the project is inactive. By the same token, there is an increased value in “waiting it out” if margins are falling and management is considering shutting down. The lesser the uncertainty over future prices (smaller  $\sigma$ ), the smaller the investor’s inaction gap — waiting to make an entry or exit decision is less valuable

for the investor who holds good knowledge about the future direction of the market than it is for an investor who faces high uncertainty.

#### 4.2.b Sensitivity to Entry Costs

Table 8 shows the dependence of the entry and exit gross margin triggers on sunk entry costs  $I$ .

| Table 8. Sensitivity to Sunk Entry Costs |     |            |       |        |       |       |       |         |       |
|------------------------------------------|-----|------------|-------|--------|-------|-------|-------|---------|-------|
|                                          |     | 50 mm gall |       |        |       |       |       |         |       |
|                                          |     | ROA        |       |        | NPV   |       |       | NPV-ROA |       |
|                                          | $I$ | $P_H$      | $P_L$ | Gap    | $P_H$ | $P_L$ | Gap   | $P_H$   | $P_L$ |
|                                          | 167 | 150.03     | 44.15 | 105.88 | 61.20 | 44.67 | 16.52 | -88.83  | 0.52  |
| Benchmark                                | 185 | 154.81     | 43.38 | 111.42 | 62.82 | 44.51 | 18.31 | -91.99  | 1.13  |
|                                          | 204 | 159.76     | 42.64 | 117.12 | 64.53 | 44.34 | 20.19 | -95.23  | 1.7   |
|                                          |     |            |       |        |       |       |       |         |       |
|                                          | 154 | 143.81     | 43.40 | 100.41 | 58.83 | 43.60 | 15.24 | -84.98  | 0.2   |
| Benchmark                                | 171 | 148.36     | 42.64 | 105.72 | 60.36 | 43.44 | 16.92 | -88     | 0.79  |
|                                          | 188 | 152.83     | 41.94 | 110.89 | 61.89 | 43.29 | 18.60 | -90.94  | 1.35  |

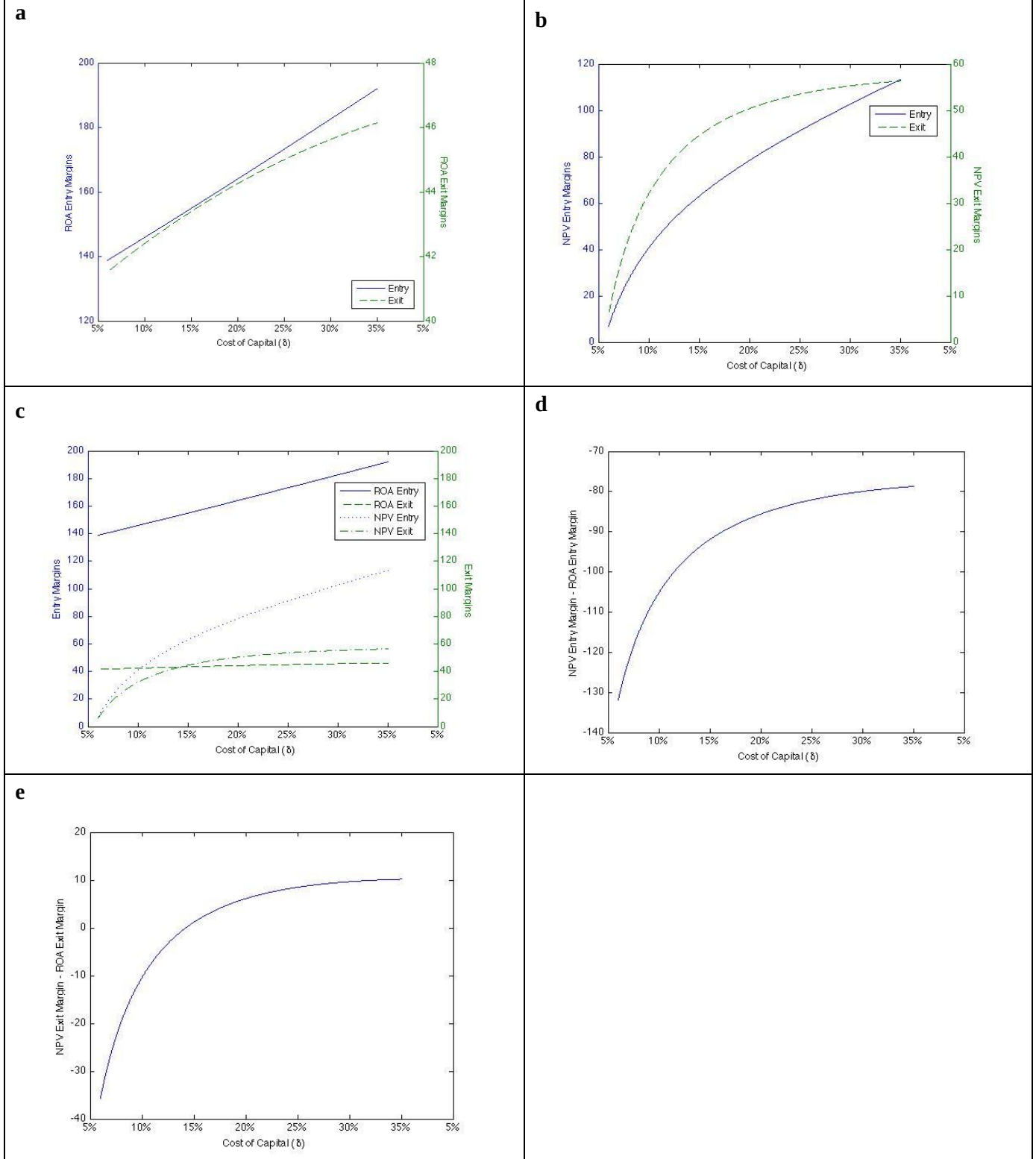
As expected, larger sunk entry costs increase the entry gross margin trigger and lower the exit gross margin trigger- this is true under both the ROA and the NPV approaches. The difference between the ROA and NPV is much larger for the entry gross margin trigger than it is for the exit trigger. Further, the difference between entry margin trigger under both approaches grows larger as sunk entry costs increase. Again we observe that the inaction gap is considerably larger under the ROA than under the NPV approach although logically, entry trigger prices are much more sensitive to changes in sunk investment costs than exit trigger prices.

#### 4.2.c Sensitivity to Cost of Capital

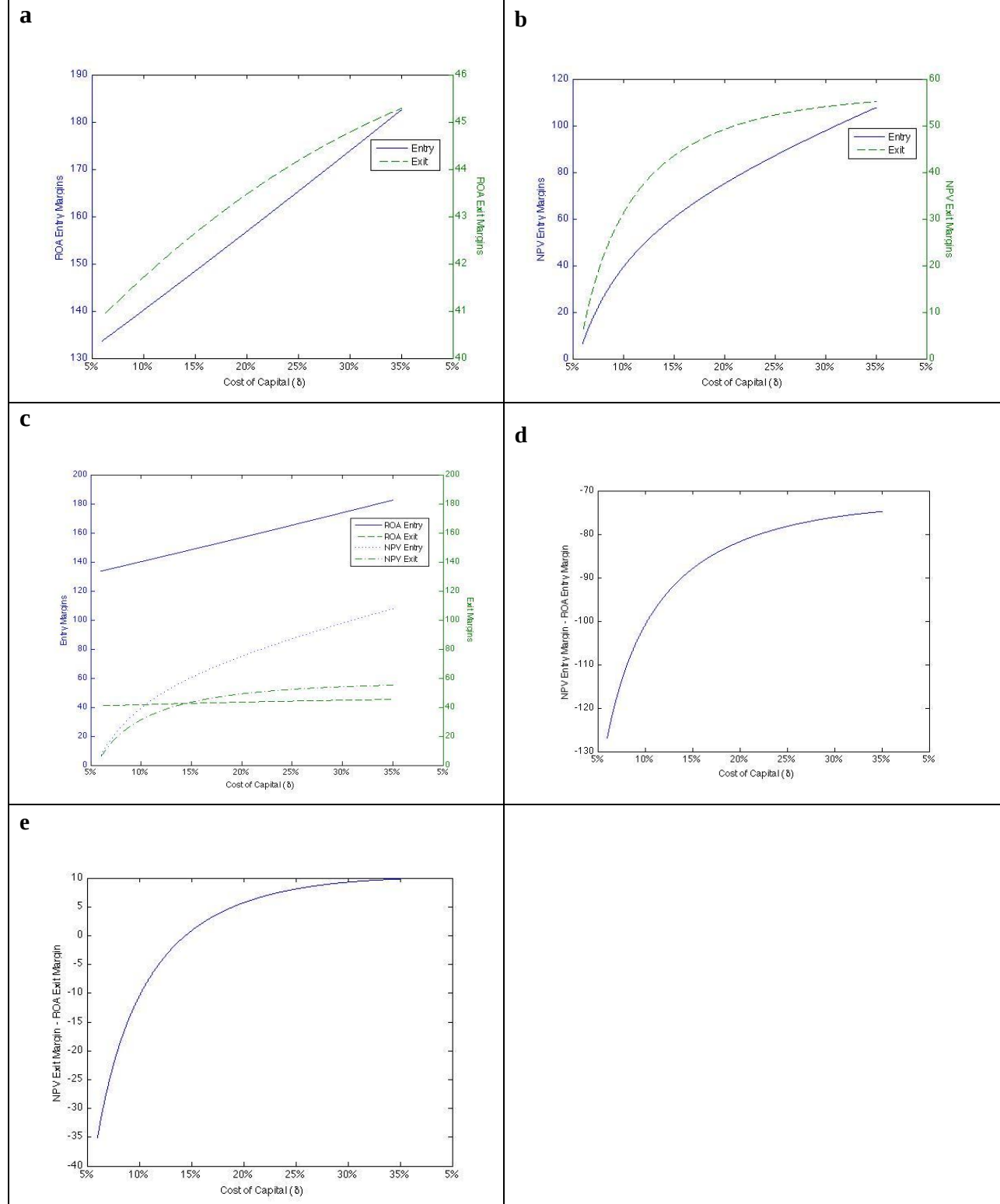
As shown in figures 6 and 7 an increase in the cost of capital  $\delta$  increases both the optimal investment trigger  $P_H$  and the disinvestment trigger  $P_L$ . The cost of capital represents the rate of return an investor would earn in an alternative investment with similar risk. An increase in  $\delta$  makes the option to invest more valuable and consequently increases the opportunity cost of investing now. In other words, the greater the return an investor can earn from projects of similar risk, the less tolerant he/she will be of unfavorable market conditions. Other things held equal, increasing cost of capital means investors will be less willing to invest in a project and more ready to disinvest once the project is live.

From figures 6c and 7c, notice that for large values of  $\delta$ , the inaction gap grows considerably under both methods. Notice also that the inaction gap is wider under the ROA than it is under the NPV approach. Because the ROA takes into consideration the value of waiting, an investor using this approach requires a much greater stimulus to make investment/disinvestment decisions.

**Figure 6 a-e. Sensitivity to the Cost of Capital for the 50 million gallon plant.**



**Figure 7 a-e. Sensitivity to the Cost of Capital for the 100 million gallon plant.**

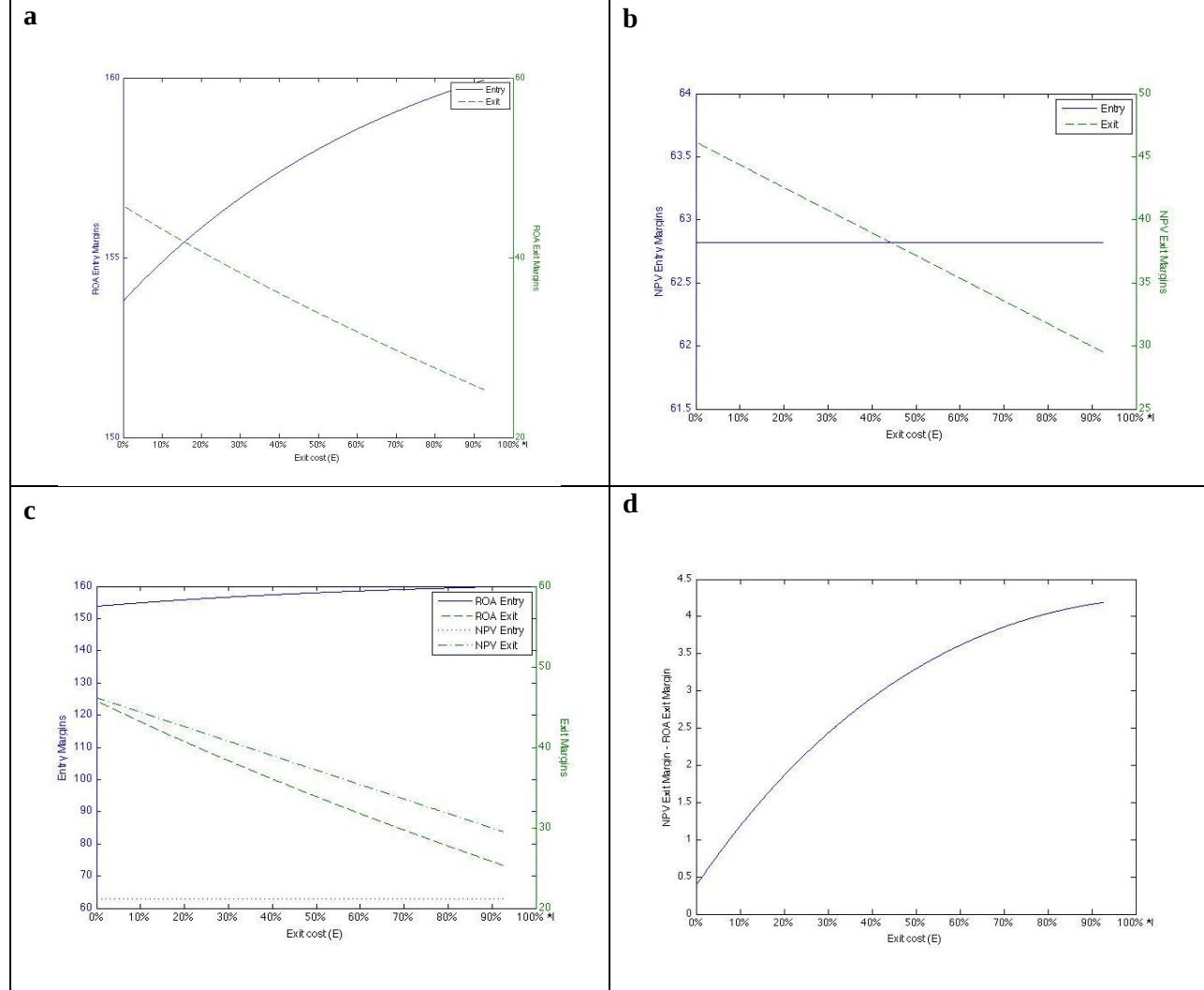


Figures 6d and 7d plot the difference between the NPV and ROA entry margins against the cost of capital,  $\delta$ . Notice that for low values of  $\delta$ , the ROA entry margin is much higher than the NPV entry margin; the difference gets smaller as the cost of capital increases, but the ROA entry margin is still higher than the NPV entry margin. Figures 6e and 7e show that for low values of cost of capital, the ROA exit margin is higher than the NPV exit margin; as the cost of capital increases the ROA approach yields a lower exit margin than the NPV approach. These examples show once more, that in the face of uncertainty, the ROA approach results in more conservative investment decisions than the NPV approach. This is also true for exit margins (figures 6e and 7e). As the cost of capital increases, the ROA and NPV approaches yield increasingly disparate results.

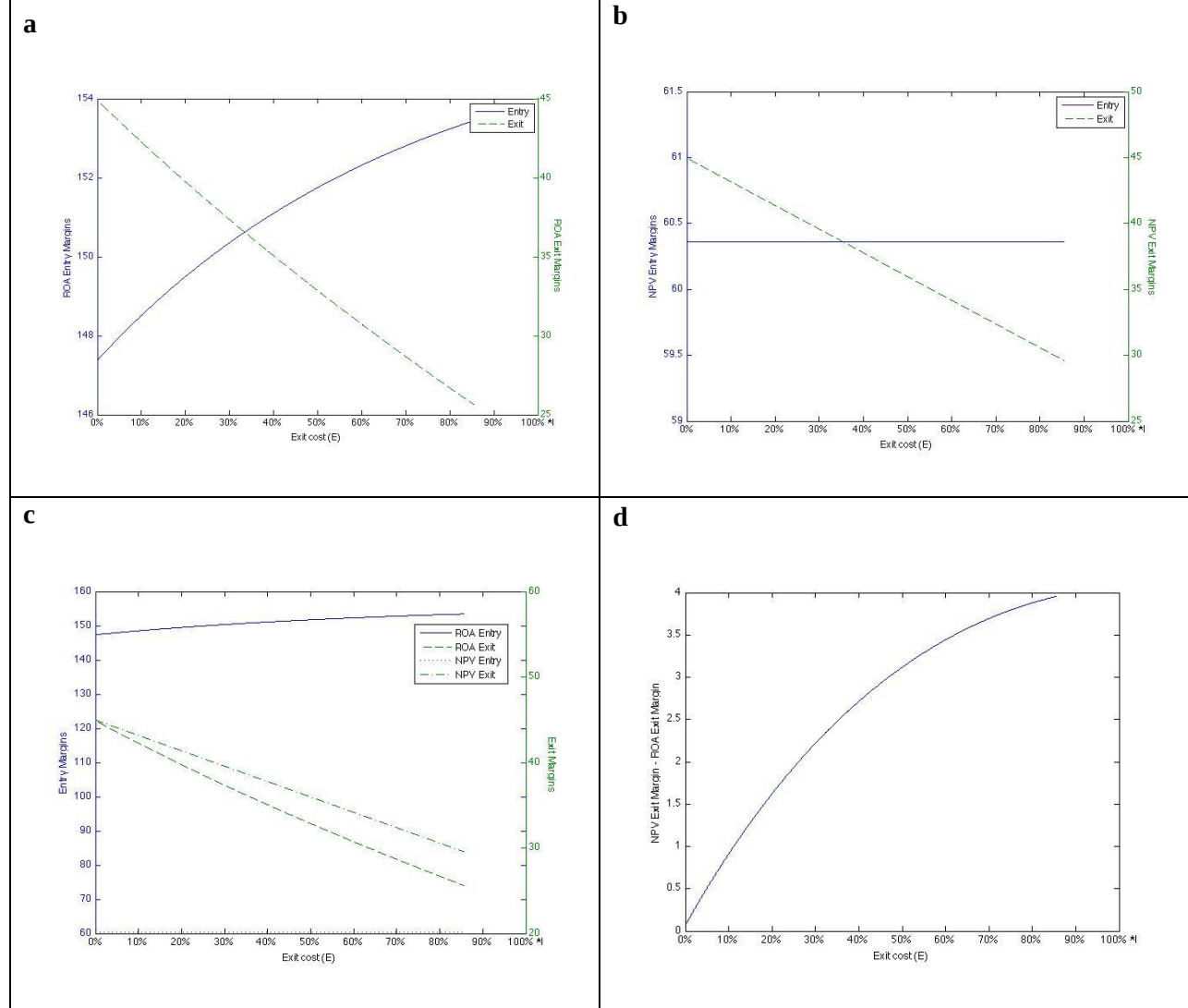
#### **4.2.d Sensitivity to Exit Costs**

Figures 8 and 9 show that under the ROA, as exit costs  $E$  increase, the gross margin entry trigger  $P_H$  also increases. For any gross margin  $P$ , a higher exit cost in effect reduces the value of the option to abandon the operating ethanol plant; therefore, it reduces the value of the project as well. This means that the gross margin obtained is required to be higher before the project is undertaken. Similarly, higher exit costs lower the gross margin exit trigger  $P_L$ ; investors must pay more to exercise their abandonment option, for that reason gross margin is required to drop further before the project is abandoned.

**Figure 8 a-d. Sensitivity to exit costs for the 50 million gallon plant.**



**Figure 9 a-d Sensitivity to exit costs for the 100 million gallon plant.**



## CHAPTER 5

### CONCLUSIONS

The push to promote the development and use of biofuels to meet U.S. energy requirements stems from the uncertainty in world energy markets, the dependence of the U.S. on oil imports, concerns about greenhouse gas emissions from fossil-based fuels, and search for new uses of agricultural commodities. Moreover, general support for biofuel development has resulted in government issued ethanol production mandates, processing corn subsidies, and fuel-blending requirements. Given the requirements outlined in the EISA 2007 and the fact that corn has been the most commonly used feedstock during early U.S. biofuel production, corn based ethanol will likely remain a key element of the biofuel portfolio (Malcolm et al. 2009).

The objective of this thesis has been to evaluate entry and exit investment decisions for an ethanol plant in Georgia under a real options framework and compare the results to those obtained under the traditional net present value approach. Dixit and Pindyck's model of a firm's entry and exit decisions under irreversible investment and price uncertainty is used to model entry and exit ethanol margin thresholds.

We evaluated entry/exit decisions on two different size conventional ethanol plants: a 50 million gallon/year and a 100 million gallon/year plants. Results suggest that investors using the NPV approach tend to "react excessively" to margin stimuli: the gap between entry margin and exit margin is smaller than under the ROA. By considering the stochastic nature of the ethanol margin, the irreversibility of investment in the ethanol plant, and the possibility to delay the

investment /disinvestment decisions, the ROA yields much more “cautious” thresholds--- the inaction gap is shown to be consistently larger when using the ROA.

Using the real options approach we obtained trigger entry margin  $P_H$ , of 154.81¢/gallon for the 50 million gallon plant and 148.36¢/gallon for the 100 million gallon plan; and trigger exit margin  $P_L$  of 43.38¢/gallon for the 50 million gallon plant and 42.64¢/gallon for the 100 million gallon plant. Using the more traditional NPV approach, we obtained entry trigger gross margins of 62.82¢/gallon and 60.36¢/gallon for the 50 million and 100 million gallon plants, respectively. The NPV approach yields trigger gross margin for exit ( $P_L$ ) of 44.51¢/gallon and 43.44¢/gallon for the 50 million and the 100 million gallon plants, respectively.

Sensitivity analyses were conducted for the drift rate  $\alpha$ , volatility parameter  $\sigma$ , entry costs, cost of capital, and exit costs. Results from sensitivity analysis on the drift rate show that the larger the drift parameter, the smaller the inaction gap under both the ROA and NPV approaches. However, results also show that a firm using the NPV approach exhibits more “reactive” behavior, investing sooner when the drift is high and exiting more readily when drift is low.

Conversely, sensitivity analysis on the volatility parameter show that greater gross margin volatility causes the inaction gap to expand- as volatility of gross margin increases, there is increased value in waiting since margins can change rapidly. We also find that larger sunk entry costs increase the entry gross margin trigger and lower the exit gross margin trigger under both the NPV and the ROA approaches. Further, a firm invests and disinvests more readily under the NPV approach than under a ROA framework.

Sensitivity analysis on the cost of capital  $\delta$  shows that an increase in  $\delta$  increases both the investment trigger and the disinvestment trigger. As expected, the investment trigger is much

more sensitive to changes in  $\delta$  and once again, we find the inaction gap to be much wider under the ROA than under the NPV approach. Finally, sensitivity analysis on exit costs show that under the ROA, an increase in exit costs results in an increase in the gross margin trigger for entry and lowers the gross margin trigger for exit.

In light of the recent bankruptcy of the biggest ethanol plant in the state of Georgia, we are reminded of the uncertain economic climate in which biofuel producers must operate and make investment decisions. Improved risk management and capital valuation methods must be used in order to minimize investment risk. Real options approach provides an alternative to conventional investment strategies that both limits downside risk and takes better advantage of upside potential. The results obtained in this analysis suggest that using a real options approach as a strategic decision making tool might allow investors to make improved and better timed investment and abandonment decisions.

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