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Using Real Options to Evaluate Investment Decisions in Ethanol Facilities

Master's Program: Plan B

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Abstract

This paper uses binomial option pricing model, which is a discrete time model for real option analysis, to evaluate the investment decisions (real options) in ethanol facilities. The base case model is for a hypothetical ethanol plant with production capacity of 50 million gallon. The evaluated real options include (1) a 15 million gallon expansion for a conventional ethanol plant, (2) the option to choose starting a stover ethanol plant versus a conventional ethanol plant, and (3) the option to choose starting a stover-plus ethanol plant versus a conventional ethanol plant. Price data for corn, natural gas, and ethanol are collected and Monte Carlo simulation is used to generate historical cash flows. Scenario analyses are done to apply different volatility of present values and initial asset values to the option to expand. The different volatility and initial asset values are based on the generated cash flows of the project for different periods in the history. The results show that with lower volatility and higher initial asset values, the expansion project may be more favorable to ethanol investors. The results of binomial option pricing model for options (2) and (3) show that the plants with stover-based technology are chosen more frequently by the model, compared to the conventional ethanol plant.

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Using Real Options to Evaluate Investments in Ethanol Facilities

Chapter 1 Ethanol Industry Overview

Ethanol, also known as ethyl alcohol, is used as an additive to gasoline to help reduce the greenhouse emissions. In the U.S., most ethanol products are produced from corn as feedstock and natural gas as boiler fuel using dry-milling technology. However, with increasing prices of corn and natural gas, and other environmental problems caused by ethanol, the investments in ethanol plants are facing more uncertainty in the future. By reviewing the developments of ethanol industry in the US, we will introduce the competitiveness of ethanol as a transportation fuel and the rising uncertainty in the investments in ethanol facilities. Then, by comparing with the traditional net present value (NPV) analysis, the advantages of using real options analysis for investment decisions will be discussed and the objectives of this study will be introduced.

1.1 Developments of Ethanol Industry in the U.S.

The increasing demand for energy and the deteriorating air quality of the world lead to innovations in transportation fuels in the last several decades. The fuels tend to be more environmentally-friendly and more of them are from renewable sources. Fuels that are produced from renewable biological sources and contain certain energy content are defined as biofuels, or renewable fuels.[1]

[1]Oxford University Press, “A Dictionary of Biology”, 2004.

Biofuels can be gaseous, liquid, or solid. Ethyl alcohol with the chemical formula CH_3CH_2OH, usually known as ethanol, is one type of liquid biofuels. Ethanol is traditionally produced from agricultural resources or wastes. Specifically, speaking of transportation fuels, a mixture of gasoline and ethanol is used as an alternative fuel for cars and other vehicles in many countries. For example, E10 is a mixture of 10% ethanol and 90% gasoline while E85 is a mixture of 85% ethanol and 15% gasoline. These mixtures are expected to be more “clean-burning”, that is, the emissions of burning ethanol in an engine will cause less greenhouse effect than petroleum.

Historically, another additive, Methyl Tertiary Butyl Ether (MTBE) played the role of reducing the greenhouse effects by transportation fuels. It is an oxygenate made from natural gas and petroleum. MTBE dominated the market of oxygenate in early 1990’s until later found to be contaminating underground water, endangering to human and the environment. It has been banned in many states since then. By the late 2006, most petroleum companies and retailers stopped using MTBE as an additive to gasoline, because of the observed contaminant to underground water by MTBE.

With the fade-out of MTBE, ethanol has become more important in the biofuel market. The production of ethanol is growing with a dramatically high rate in the last five years or so. The ethanol industry in the U.S. has grown into a big and mature market during the last 30 years. In the year 2005, 94 ethanol plants located in 19 states produced 4 billion gallons of ethanol, which is a 17% increase from 2004. By 2012, the production in the U.S. will be doubled by the Renewable Fuels Standards (RFS) legislated in 2005. In

January 2006, there were 31 ethanol plants under construction, which contributes to about 30% of the total existing plants.

In the U.S., ethanol is primarily produced from the starch contained in grains such as corn, grain sorghum, and wheat. Through a fermentation and distillation process, the starch is converted into sugar and then into alcohol. Most ethanol plants in the U.S. are using dry-milling process with corn as feedstock. As a matter of fact, in 2005, 79% of ethanol production in the U.S. is provided by dry-milling plants with corn as the main feedstock.

As a mature industry in the U.S., ethanol industry has its attractions to investors because there are favorable factors for high profitability, especially in the last several years. Since 1978, ethanol blenders have received an excise credit from the federal government under the Energy Tax Act of 1978. The Small Producers Credit established in 1990 has also encouraged ethanol production. In 2005, the Energy Policy Act legislated the Renewable Fuels Standards (RFS) calling for the consumption of biofuels to reach 7.5 billion gallons by 2012. These policies contribute to the growing investments in ethanol facilities.

These favorable factors have led to the rapid growth of the ethanol industry in recent years. In 2006, over 30% of the plants under construction have a production capacity of 100 million gallons per year. This causes the increased capital investments in the ethanol industry. On the other hand, the investor structure is also changing due to the expanding scale of ethanol plants. Local co-op equity investors are being replaced by large financial institutions, commercial banks and private equity firms capable to fund large-scale ethanol construction projects. The debt services schedules and the required financial returns will be no longer the same as before. That is, the interest rates and retirement for construction loans will have higher expectations and variations in the future.

With all these facts in the biofuel industry, the uncertainty of producing ethanol has been rising. The profitability of producing dry-milling ethanol is not as high as before, although the policies are still favorable to ethanol investors. Therefore, it is necessary for investors to reevaluate the competitiveness of grain ethanol product.

1.2 Competitiveness of Ethanol as a Biofuel

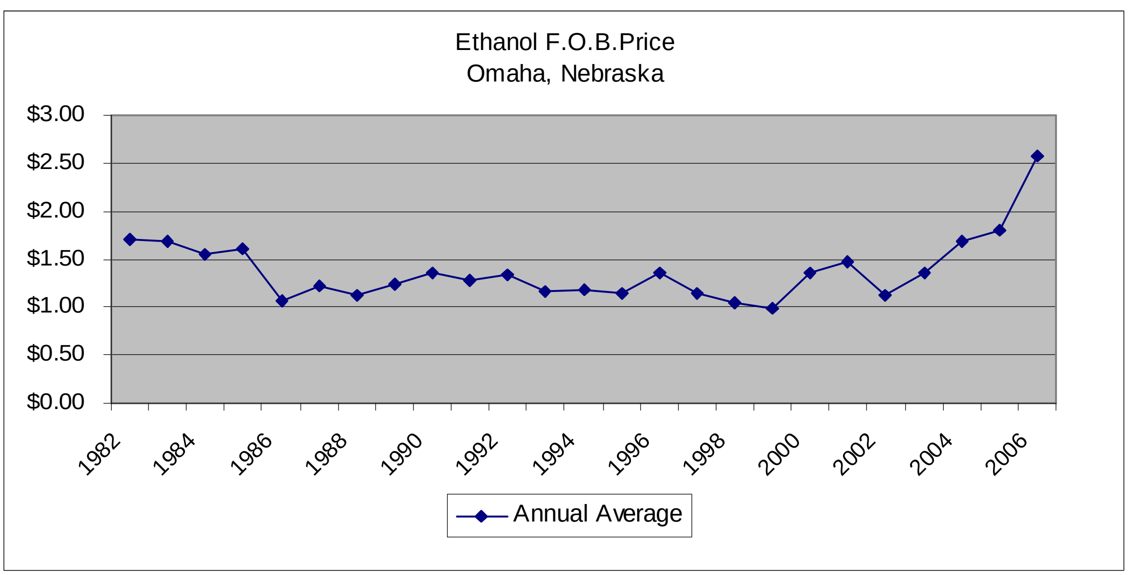
The competitiveness of ethanol actually leads to price uncertainty in producing ethanol. Although some investors have accepted ethanol as a relatively safe long term investment, there exists uncertainty in the cost structure. The first uncertainty is from the corn cost for dry-milling ethanol plants in the U.S. The expanding scale of the ethanol industry causes higher demand for corn. The price of corn has also been driven to a higher level. In the last ten years, the average annual growth rate of cash price of corn in Chicago is about 6.5%, however, there is about 85.3% increase from 2006 to 2007. This is the highest annual growth rate of corn price in the last ten years. During the same period, the domestic utilization of corn has only increased about 2.9%.

The second uncertainty is from the cost of energy. For a typical dry-milling ethanol plant, the natural gas consumption to produce a gallon of ethanol ranges from 26,000 to 54,000

BTU (USDA, 2002). This energy cost represents a large portion in the cost structure for dry-milling ethanol plants. From 2004 to 2005, the energy cost is about 15% of the total cost in unit of dollars per gallon of ethanol produced, the second highest cost after corn cost (Christianson and Associates, 2005). The natural gas price in 2006 is about two times what it was in 1996. All these factors lead to higher volatility in corn and energy supply and, consequently, a more volatile profitability of ethanol.

If one looks at the output prices of a dry-milling ethanol plant, there is also uncertainty in ethanol prices. The annual average ethanol F.O.B. prices in Omaha, Nebraska from year 1982 to 2006 have a standard deviation of $0.34/gallon. The plot of the annual ethanol price from 1982 to 2006 is given in Figure 1.1. This is not as high as the standard deviation of corn price in the same period, which is $0.50/gallon, but from the chart we can see that the ethanol price in 2006 exceeds the average level of the years before.

Figure 1.1 Ethanol F.O.B. Price, Omaha, Nebraska, 1982-2006



As a matter of fact, all the monthly ethanol rack prices in 2006 (Omaha) are highest compared to the prices in the same months in the last 24 years (1982 – 2005). With the increasing rack price, will ethanol be as competitive as it was before? Will the profitability of producing ethanol be affected by this fact? How much will the profitability be affected? These are the questions that investors should think about more carefully when making decisions on investing in ethanol facilities.

Furthermore, the mileage of burning ethanol as a transportation fuel has also been questioned by the public, because ethanol has lower energy content than gasoline. For example, E85 (85% ethanol and 15% gasoline) has 24.7% less energy content than gasoline. If ethanol loses its advantage in low price and without government mandates to use alternative fuels, it is natural for consumers to choose transportation fuels providing higher mileage to their vehicles.

For a traditional corn-based dry-milling ethanol plant, one of the prevalent marketable byproducts is distiller's grains. The distiller's grains can be distiller's dried grain with solubles (DDGS) or distiller's wet grain with solubles (WDGS). Approximately 60% of distiller's grains is DDGS and marketed domestically and internationally for use as dairy, beef, swine and poultry feeds (Department of Animal Science, University of Minnesota). About ten years ago, revenue from distiller's' grain comprised almost one-third of the average ethanol facility's total revenue. But with the energy bill, tax credits and soaring ethanol markets, in 2005, distiller's' grains brought in less than 10 percent of the total revenue. What is more, the level of protein contained in distiller's' grains, especially

DDGS, is not as high as required by livestock and poultry production. Producing high protein distiller's grains has an expected higher return but also a higher cost, since additional technologies, equipment and labor will be required. Therefore, the significance of DDGS/WDGS revenue needs to be reevaluated in order to consider the changing situation in the feed grains market. This fact adds more to the uncertainty of return of an ethanol asset.

Due to the increasing price of corn and the appeal for more corn for food instead of fuel, the demand for alternative sources to produce ethanol is also rising. As a matter of fact, researchers and the federal government are now working to develop the "Second Generation Biofuels", which includes lignocellulosic and cellulosic ethanol. The second generation biofuels distinguishes from the conventional ethanol made from grain feedstocks today. Actually, different geographical and natural recourse conditions lead to different feedstocks to produce ethanol. For example, in tropical or subtropical countries such as Brazil, sugar cane is used to produce ethanol. In the U.S., researchers are developing technologies to produce ethanol from biomass. The development of substitutes for grain feedstock would be a threat to the survival of conventional ethanol plants in the future. This is another fact that will add uncertainty to the return on conventional ethanol plants.

Regardless of the price risks and eliminations by alternative feedstock technologies, the competition between ethanol and its substitutes is getting more intense in biofuel markets. Although ethanol has been recognized as a clean-burning, environmentally-friendly transportation fuel, deficiencies in producing and using ethanol have been found by some ecologists and environmentalists. According to Hill, et al (2006), corn-based ethanol is found to be less efficient in net energy balance (NEB) compared to soybean-based biodiesel. The paper also claims that growing corn will cause more environmental problems than growing soybeans. Biodiesel production in 2004 was 25 million gallons and it had increased to 75 million gallons in 2005. From 2004 to 2006, the US Department of Agriculture offered the grants of $1.45-$1.47 per gallon to the soybean oil biodiesel production through the Commodity Credit Corporation (Radich, 2004) Energy Information Agency gave out a 6.5 million gallons estimation of biodiesel production in 2012. With biodiesel being realized as a better energy source, the market share of biodiesel product will be increasing and it will add more competition to ethanol products.

As many other types of single-purpose facilities in agriculture, the plants producing dry-milled ethanol products can hardly be converted to other uses. If the ethanol markets are shrinking so that some ethanol facilities are facing elimination before expected expiration, it will be difficult to obtain compensations.

Although there is uncertainty that will affect profitability of producing ethanol from grain feedstock, technologies of improving production efficiencies for these conventional plants are also in progress. These technologies can be built onto existing dry-milling equipment. For example, corn fractionation for dry-milling ethanol plants can produce more byproducts such as corn oil and edible fiber; this technology can also help increase the production of ethanol and the concentration of protein in distiller's' grains. Other examples are technologies for using biomass as boiler fuels for process heat to reduce natural gas consumption, since the price of natural gas is increasing and the investors are trying all the best to lower energy cost. The emerging technologies have provided new options to dry-milling ethanol plants. The valuation of these real options will give ethanol investors a sense of how to choose different technologies.

1.3 Advantages of Using Real Option Analysis

For an investment of a certain project, there are usually uncertainty of the future cash flows and flexibilities in management to deal with the uncertainty. The measurable uncertainty and flexibilities are the two conditions for real option analysis to hold. We define a real option as the right but not the obligation to make an investment decision for a project with uncertainty in the expected return on the underlying asset. For an ethanol plant, if the future returns of the asset would not vary over time, or if there were no managerial flexibilities to deal with uncertainty, a real option would not exist. We will explore how real options may improve investment decisions under conditions of uncertainty.

Traditionally, decision makers for capital investments use the net present value (NPV) method to analyze investment decisions. For example, if an investor plans to build an ethanol plant, the future cash flows (CFs) of the plant would be projected using the historical price information and the operating information of the plant. The NPV of the project at the beginning of its lifetime is calculated by

$$NPV = \sum_{i=1}^{T} \frac{CF_i}{(1+r)^T} + \frac{DCF}{(1+r)^T} - X \qquad (1.1)$$

where i = 1, 2, 3, …, T (T is the expected plant life), r is the discount rate (or hurdle rate) for the project, X is the initial investment or the construction cost of the project, and DCF is the disposal cash flow of the project. Assuming stochastic process of CFs in the NPV model is a way of incorporating volatility of CFs into the evaluation. One can use Monte Carlo simulation (MCS) to simulate values of CFs. However, this methodology can not be used to calculate the value of managerial flexibilities, while real options analysis can. An investment decision has its own value, because the flexibility of making different decisions has its value and market risks will affect this value. The market risks are usually indicated by volatility of input and output prices. According to the traditional NPV method, an investor will exercise the option to invest if the NPV of an asset is not negative. Thus, he or she might have ignored the value of waiting and might be facing violent market variations that will cause losses. Real options approach simulates NPVs by making asset returns a function of uncertainty. It is also worth mentioning that real options analysis does not really tell you how long an investor should wait, but tells you under which conditions an investor should not execute the investment, then it may be worth waiting for uncertainty to be resolved. Therefore, waiting has its own value.

A real option can be the option to start or stop a project, the option to expand or contract a project, or the options to adopt new technologies. To some extent, the options to adopt new technologies are equivalent to expansion options. For an existing plant, installment of different technologies will require capital investment and bring new cash flows. Therefore, we can view options to adopt new technologies as options to expand. As we will discuss later, it also simplifies the evaluation if treating the options to adopt new technologies as options to expand.

The method of valuing real options is similar to that of valuing financial options. There are different modelings for different needs when evaluating real options. For example, to measure the real option values at discrete points of time, one can use binomial option pricing. To measure the real options values under continuous time, one can use dynamic programming or contingent claims analysis. In order to give a more intuitive structure of the analysis, this paper will use binomial option pricing model to build binomial trees for cash flows and option values, as it will be discussed in later sections.

For medium to small sized ethanol plants, the ability of generating reasonable rate of return on invested capital is a key factor to evaluate. As we visited some of the ethanol plants in Minnesota, the plant managers indicated that they would use flat projections with price assumptions that they felt comfortable with. The sensitivity analysis for different input and output prices is used to measure the variation of future returns. The sensitivity analysis approach is helpful to analyze the returns on different levels, however, it cannot incorporate the possible price variation into the projection of return over the plant life.

We found that the tools and skills used to evaluate ethanol investments tend to vary widely and there is no “standard model” that is used in the industry for this purpose. On average, when trying to determine if a capital investment project is acceptable, plant managers and CFOs consider rate of return on the investment (ROI) and the number of years required to get payback. They also work with their lender to determine if the project is financially feasible. At the financing stage the lender typically performs additional financial analysis to evaluate the impact that prices of key inputs (such as corn and natural gas) might have on the feasibility. Some managers and CFOs use discounted cash flow methods to evaluate investments while many do not. What is more, some use “flat projections” of cash flows with various assumptions about the level of market prices and plant energy efficiency in order to incorporate aspects of price and technological uncertainty. Also, the length of cash flow projections (planning horizon) varies depending on whether it is a “greenfield” investment (5-6 years) or an investment to modify an existing plant (8-10 years). Sensitivity analysis is typically by managers to focus on profit margins under different price assumptions in order to model the variation in future ROI, yet there is no volatility analysis. The sensitivity analysis performed is helpful to analyze the expected return at different projected levels of profitability and efficiency. Probabilities could be assigned to these scenarios to give a more complete picture of the risks that are present, but it is not clear that such probabilities are employed in the typical analysis.

1.4 Objectives

The first objective of this paper is to identify the sources of uncertainty in capital investments and real options in ethanol industry. There all kinds of uncertainty in the real world of running an ethanol plant, but not all of them can be used to evaluate real options. This paper will identify the key uncertainty that will affect the real option values in an ethanol investment and how the uncertainty can be estimated and applied to the analysis.

Second, the paper will also identify the applicable real options, or, the investment plans for dry-milling ethanol plants. We will evaluate investments decisions that are applicable to current ethanol plants and prospective investors. The evaluations will be for the options to expand and the options of choosing different technologies for startups. Plant-level data will be used and a user-adjustable model will be built using binomial option pricing approach.

Third, with the results of the real options analysis in ethanol facilities, we will make recommendations and suggestions for decision makers and investors. According to the implementations of different technologies, we will estimate the volatility under each technology and evaluate the values for each option.

Fourth, we will give recommendations for why real options analysis may be useful. In section 3.1, we discuss the advantages of using real options analysis for investments in ethanol facilities. The results of real options analysis will actually show that the valuation of volatility of asset values[2] and the corresponding options values sometimes may be quite different from the intuition, since the calculation of volatility is different

[2] In this paper, asset value is just the present value of the project. Asset value and present value are interchangeably, unless otherwise stated.

from other indicators for variation (e.g., standard deviations) of asset values.

1.5 Scope of the Study

As it is mentioned in the previous section, there are about 79% of the ethanol plants in the U.S. producing ethanol product with dry-milling technology. Therefore, the subject of our study is corn-based dry-milling ethanol plant. Most of the plants are using natural gas as boiler fuels. However, with the increasing price of natural gas, alternative combustion technologies for dry-milling ethanol plants have been developed to lower the energy cost. In this paper, we will look at two alternative combustion technologies. One is using corn stover as boiler fuel instead of natural gas; the other is using a combination of corn stover and syrup instead of natural gas. These two substitutions are now considered to be less expensive than natural gas. Furthermore, it is more economical to apply the stover technologies to a startup than an existing plant, so we will look at the options of choosing different combustion technologies for building a new plant.

For the options to expand, our study will focus on ethanol plants with relatively smaller size. Most ethanol plants in Minnesota are of median size or smaller. The base case model is built for a dry-milling ethanol plant with capacity of 50 million gallons per year (mm gpy). The expansion will be 15 mm gpy, which is an applicable number for a median size ethanol plant. The historical prices used in our analysis are from 2001 to 2007, so our research will recapture the volatility of ethanol asset values for this specific period.

1.6 Organization of the Study

The first chapter of this paper introduces the development of ethanol industry. The problems and concerns on investment in ethanol have been discussed. The corresponding real options were also introduced. In the second chapter of this paper, we will review the studies done in economic issues with ethanol. The studies done in real options analysis will also be reviewed. Chapter 2 will provide a basis for the unsolved problems in ethanol industry and how to use real options approach to analyze the problems in investments. Chapter 3 will introduce the functional model for real options. We will use binomial option pricing model (BOPM) to evaluate the real options. BOPM is a discrete time model and there are two approaches to solve the model, one is replicating portfolio approach and the other is risk-neutral probability approach. In our analysis, we will use risk-neutral probability approach to resolve the model. In chapter 4, we will discuss the methods of calculating the parameters in BOPM and the historical data used to calculate the parameters. Chapter 5 will be the simulations and analysis of the real options. The real options include the options to expand and the options to choose between different combustions technologies. The conclusions will be drawn in chapter 6. The recommendations and suggestions for investors will also be made in chapter 6.

Chapter 2 Review of Literature

This chapter reviews some of the previous studies in economics of ethanol plants and ethanol industry, as well as some of the previous studies in real options, especially the ones in agribusiness sector. The purpose of this chapter is to provide a basis for the unsolved problems in ethanol economy and how we may analyze these problems using real options approach.

2.1 Economics of Ethanol Plants

Tiffany and Eidman (2003) study the factors that will significantly affect the profitability of dry-milling ethanol plants. The base case model is on a plant with 40 mm gpy production capacity. Using sensitivity analysis, they draw the conclusion that the key factors are corn price, ethanol price, natural gas price, conversion factors, and capacity factor. The conversion factors include corn consumption per gallon of ethanol production, natural gas consumption per gallon of ethanol production, etc.. They test the sensitivity of profits to each individual factor, as well as to the effects of multiple factor interactions (such as corn-ethanol price combination, natural gas-corn price combination). For example, with a 40 mm gpy capacity, the annual profits are enhanced by 165 thousand dollars for each 0.01 dollars decline in corn price and 480 thousand dollars for each 0.01 increase in ethanol price.

In addition, Tiffany and Eidman also conclude some other factors that are not as important in affecting the profits of an ethanol plant. Those include: price of dried distiller's' grains (DDGS), price of electricity, capital costs, percentage of debt, and interest rates. Specifically, they also study how the potential cash sweeps would affect the debt schedule of an ethanol plant. The assumption for the debt schedule is ten-equal-annual payments. When favorable returns occur in a certain year, lenders may allow ethanol plants to apply cash flow sweeps to increase principal payments. In this way, interest expense and cash dividends can be reduced, and the loan can be paid off earlier. Tiffany and Eidman' s paper gives a good evaluation of key factors that affect the profitability of ethanol plants, and demonstrates the importance of cost control, risk management and adoption of new technologies. Based on their results, our research set ethanol price, corn price, and boiler fuel price as variables when estimating the historical cash flows (CFs), while keep other prices and costs as constant, since the others are not likely to affect the profitability of an ethanol plant significantly. However, the sensitivity analysis model built by Tiffany and Eidman is static in its treatment of some economic factors, such as risks and time. Our research will enhance Tiffany and Eidman' s model by implementing risk simulation over life time of an ethanol plant. The volatility of present values of an ethanol asset will be evaluated by allowing the three key prices to vary, and the volatility value will be applied in the real options analysis. Thus, the sensitivity of asset value and option values to the risk factor can be detected.

Coltrain et al. from 2001 to 2004 have done a series of reviews and studies on economic issues in ethanol industry. In the papers of Economic Issues with Ethanol (2001) and

Economic Issues with Ethanol, Revisited (2004), Coltrain et al. introduce the economic input and output factors for an ethanol plant. These factors include the prices and quantities of ethanol, grain feedstock, distiller grains, natural gas, etc.. Specifically, they indicate that the DDGS price is related to the price of grain feedstock and concluded that DDGS revenue contributes significantly to total revenues of an ethanol plant. In the paper of Risk Factors in Ethanol Production (2004), Coltrain et al. argue that there are risks in processing technology, operation, and marketing. Coltrain et al. study the relationship between prices of inputs and outputs, using factor relationships to determine the nature of the risk. To compare factor relationships, they used correlation coefficient of input prices and output prices of ethanol products. Coltrain et al. also argue that the highest risk for two or more outputs would be associated with the perfectly positive correlation of one and the lowest risk with the perfectly negative correlation of minus one. The highest risk for an input and an output combination would be a negative correlation of one and the lowest risk would be a positive correlation of one. A correlation of zero signifies that the compared factors have no relationship.

Coltrain's analysis for correlation coefficient conceptualized the risk factors affecting profits of an ethanol plant. According to the study, the four major market risk factors for an ethanol plant are the prices of ethanol, distiller's' grains, grain feedstock (corn or sorghum) and natural gas. First, however, Coltrain does not quantify the effects by these risk factors on profit or cash flows; second, he does not discuss the management options to deal with these risk factors; third, he does not evaluate the option values.

Richardson et al. (2007) have done a case study for ethanol production in Texas. They use Monte Carlo simulation to analyze the risk in ethanol investment. The results for deterministic case and stochastic case were reported, including the cost of production, average annual net return, average annual ending cash reserves, net present values, rate of return on investment, etc.. The probability of economic success was also reported. The contribution of this study is to provide a methodology that explicitly incorporates risk faced by investors. The probability distribution of key output variables were defined, so that the investors can see the ranges of these variables and the probabilities of unfavorable outcomes.

Richardson's study demonstrates the advantages of simulation risk analysis. It provides an access to measure the flexibility in the investment of a proposed agribusiness. Because of the variation of profit from ethanol industry in recent years, it is important for the investors to take uncertainty into account. So Richardson's study has established the fundamentals for risk analysis for economics in ethanol industry. The use of Monte Carlo simulation will resolve the economic problems in agribusiness involving stochastic process. Yet, Richardson et al. do not define what the flexibilities are in managing ethanol investments, while it is also important that an investor can have the knowledge of investment options and reasonable evaluations for them. In our analysis, we will use Monte Carlo method to fitted distribution to historical CFs. Thus, the expectation of CF can be determined and the distribution of CFs can be used to simulate random sample values for calculating the asset value. Therefore, the volatility of asset values can be estimated using the distribution of the CFs, and the asset values under volatility can be evaluated. The value of the options dealing with the underlying uncertainty can also be estimated. In fact, this is just the purpose of real options analysis.

Morey et al. (2007) study the biomass technologies to produce heat and power for dry-milling ethanol plants. For conventional dry-milling ethanol plant, natural gas is the mostly used energy for process heat and combustion. However, the increasing energy cost has stimulated the investors and researchers to seek for less expensive substitutes for natural gas. Morey et al. model the technical integration of several biomass energy conversion systems into the dry-grind ethanol process. The biomasses include corn stover, the combination of corn stover and syrup, and the gasification of DDGS. Although the performances of efficiency and air emissions vary, the research results suggest that all the three methods could be used to generate process heat and electricity for ethanol plants. Morey's results are helpful for developing real options on choosing different technologies to lower the energy costs of ethanol plants. The real options in our analysis are based on the results by Morey et al. We analyze the option to choose stover combustion versus natural gas combustion and the option to choose stover-plus-syrup combustion versus natural gas combustion. Tiffany (2007) builds a model for estimating the costs and revenues of ethanol plants with these three technologies. Setting the annual production to be constant, Tiffany analyzed the rate of return (ROR) for the plant under each technology. He also does sensitivity analysis to compare the ROR for each type of plant under different price levels of ethanol, natural gas, and corn. Tiffany's estimates for the costs and revenues have established a baseline model for our real options analysis. We estimate historical volatility and incorporate the volatility value into evaluation of the ethanol asset under different technology. Thus, the economic risk regarding these technologies and the option values are estimated. So investors can make decisions under uncertainty.

2.2 Real Options Analysis

In corporate finance, real options analysis incorporates evaluation techniques of financial options into capital budgeting decisions for real assets. Uncertainty in the future cash flow of an investment and managerial flexibility to deal with the uncertainty are the two sufficient conditions for a real option to exist. For example, an ethanol plant manager plans to expand the annual production by installing some new technology to improve the production efficiency. The capital budget allows the investor to install the equipment either in the current year or any year in the next six years. However, when the manager looks at the high variance of historical prices of input and output, she is skeptical about the profitability of the expansion project in the future. Now, the manager has the right to either execute or reject the investment decision for the new technology, or to wait until next year to see if the uncertainty will be settled. This right is just a type of real options. To decide when to exercise the option, we can use the historical data to calculate the volatility and estimate the present values of the project under the expected volatility. If we use discrete time model, the evaluation of the real option in this example is similar to that of an American call option. So, real options have the same characteristics as financial options. The difference is that the underlying assets for real options are real assets and the real options are usually not tradable. One can also use continuous time model to estimate real option values. More on the derivation for real options method will be introduced in chapter 3. In this section, we will review the previous work done in real options and see how the real options models were developed to solve the problems, especially the ones in agribusiness.

Copeland and Antikarov (2001) introduce the binomial lattices method to evaluate real options and compare it with net present value (NPV) method and decision tree method in their book, Real options - a Practitioner's Guide. In this book, they model simple options using binomial option pricing model (BOPM), including the abandonment options and the options to contract (valued as American put options), and the options to extend the project life (valued as American call options). Copeland and Antikarov's work has set good examples of applying BOPM to real options evaluation. They also coin the term *Marketed Asset Disclaimer* (MAD) in their book. The MAD assumes that the traditional present value of cash flows of a project can be used as the price of underlying risky asset. They also give examples to support the feasibility of this assumption. They argue that the MAD makes assumptions no stronger than those used to estimate the project NPV, but the distribution of rates of return on the priced securities is correlated with the project sufficiently well to be usable. Since real options are not like financial options, the underlying assets and the options themselves are usually not tradable and they do not have marketed prices, this MAD assumption provides a good support for using BOPM to evaluate real options like financial options. Mun (2002) also discusses the BOPM method for evaluating real options in his book of Real Option Analysis – Tools and Techniques for Valuing Strategic Investments and Decisions. Examples are given for different types of options and the use of software is also introduced.

Other than discrete models, continuous time models are also used quite often for valuing real options. Dixit and Pindyck (1996) in their book of Investment under Uncertainty discuss the methods of dynamic programming and contingent claims analysis for evaluating real options. The value of the underlying asset is assumed to follow geometric Brownian motion (GBM). The growth rate of the asset value (the “drift” parameter) and the standard deviation of the asset value (the variation parameter) are derived from the GBM. These two parameters are used to determine the optimal investment trigger value of the underlying asset. More will be introduced on the introduction of continuous time model in chapter 4. We will review some studies using continuous time model to evaluate the real options.

Engel and Hyde (2003) use real options approach to study the investment for automatic milking systems in the U.S. They used the ex ante real options approach to simulate the cash flows associated with the automatic milking systems and develop the modified hurdle rate. The real options analysis shows that there is value of waiting, while the NPV analysis shows that one can invest in earlier years. Pederson and Khitarishvili (2002) have done the analysis of land prices under uncertainty using real options valuation approach. The traditional present value models for land pricing has been rejected as an adequate model of land price behavior, because of the inability of the model to explain the observed divergence of the returns to land from land since the 1970s. Pederson and Khitarishvili built the model using dynamic programming. Sensitivity analysis is done on the initial cash flow, the hurdle rate, the growth rate, and the net cash rent. This analysis provides a way of incorporating the uncertainty in land pricing and valuing the options under the uncertainty. Furthermore, it explains the observed divergence of land rents and prices.

Although continuous time models are widely used in real options analysis, the discrete time model is also very convenient and useful. One of the discrete models is binomial option pricing model. The binomial tree structure gives an intuitive illustration of how the asset values and the option values will be varying with the applied volatility. We will use binomial option pricing model to do the real options analysis.

Chapter 3 Real Option Model

Analogous to the way financial options are priced, the functional model for real option evaluation that we will use is the binomial option pricing model (BOPM). The BOPM assumes the investment decision (real option) can be valued as an American option. In American options, there is an expiration date of executing the option. Before the expiration date, the investor has the flexibility of exercising the option to buy or sell, or continue to hold the option (Hull, 2007). That is, the action of investment is deferrable before a certain date and the option has its own price (real option value or option value) due to the volatility of expected cash flow or value of the underlying asset.

For real options analysis, it assumes that the value of underlying asset will follow a stochastic process of “random walk” over time. The BOPM is the discrete form of this stochastic process. At each point of time during the process, the asset value will either move to one direction (up) or another (down). We consider the simplest case of random walk so the asset value will have only two directions to move from each period to the next. There are two approaches of estimating BOPM: the replicating portfolio approach and the risk-neutral probability approach. This chapter will discuss the functional models based on these two approaches.

3.1 Replicating Portfolio Approach

The replicating portfolio approach (RPA) assumes that the underlying asset can be replicated by a riskless portfolio with *m* shares of a marketable security at a known price and risk-free bonds with a value of *B*. Unlike financial options, the underlying asset of real option usually does not have a market-priced security that can be used to represent the asset value. However, we can use the present value of the asset without volatility as the market price of the asset. Copeland et al. (2003) call this the marketed asset disclaimer (MAD). For a real asset, the present value is a convenient tool of pricing and it is highly correlated with the value of asset. Therefore, the portfolio will be *m* shares of present value of the asset and risk-free bonds with a value of *B*.

In real options analysis, the option to start or the option to expand a project are usually evaluated as American call options. For example, for an investor, the option to start means that she has the right but not the obligation to start a project. Once she has decided to invest, there will be construction costs (initial investment), which is equivalent to exercise price of the option, if there are no liquidation costs. The net present value (NPV) from the investment will be the difference between present value of the asset net cash flows and the exercise price. The investor also has the right to decide when to execute the investment before a certain date (the expiration date) in the real options evaluation. Because starting or expanding a project involves the option of buying an asset instead of selling it, it is reasonable to evaluate these options as American call options.

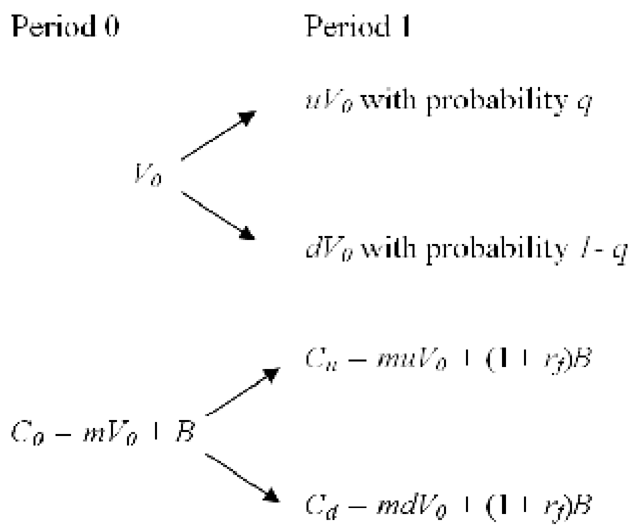
We use the option to start an investment as an example to illustrate how RPA works. Let *V* denote the present value of the asset and *C* denote the option value. Using the replicating portfolio approach, if at the initial period $V = V_0$, then the option value *C* at the same period is $mV_0 + B$ and denoted by C_0. We can examine the changes in asset values and option values after one period in a tree diagrams (see Figure 3.1).

In Figure 3.1, *u* is the up-factor and *d* is the down-factor for the asset value; *q* and 1- *q* are the "objective probabilities" that the asset value will either increase by a proportion of *u* with probability *q* or decrease by a proportion of *d* with probability 1- *q*. r_f is the risk-free rate of return. The up and down factors are determined by the following two equations:

$$u = e^{s\sqrt{\Delta t}} \tag{3.1}$$

$$d = \frac{1}{u} = e^{-s\sqrt{\Delta t}} \tag{3.2}$$

Figure 3.1 One-period Binomial Tree for Asset Values and Option Values



In equation 3.1 and 3.2, σ is the expected volatility of asset value and it could be estimated from historical data of asset values[3] and *Dt* is the increment in time for the asset value to change from one period to another and it is measured in years. If we let *T* denote the viability of the option in years and *n* denote the total number of periods that the option value will be estimated during *T*, then *Dt* = *T/n*. When valuing financial options, *Dt* is usually smaller than one because option prices are usually varying on a monthly basis. In continuous time model, *Dt* goes to zero so the option values can be estimated with instantaneous increments of time. For evaluation of real option, however, because the asset value is usually estimated annually, it is convenient to evaluate the option values at a longer increment of time such as one year. It is actually the case in our analysis, that is, *Dt* equals one since *T = n*.

[3] The definition and calculation of volatility will be introduced in chapter 4.

We can see from Figure 3.1 that from period 0 to period 1, the value of underlying asset will either increase to uV_0 or decrease to dV_0 from the initial value V_0. Consequently, the option value C will be $muV_0 + (1+r_f)B$ denoted by C_u if the asset value increases and $mdV_0 + (1+r_f)B$ denoted by C_d if the asset value decreases. In the evaluation for real options, m and B are unknown parameters that need to be solved by going backward from expiration and using the empirical values of C at expiration. In other words, we need to determine the values of C_u and C_d to solve the following equations for m and B:

$$C_u = muV_0 + (1+ r_f)B \tag{3.3}$$

$$C_d = mdV_0 + (1+ r_f)B \tag{3.4}$$

Let us assume that the option will expire at period 1. Then at period 1, the investor can either get the profit from investing or nothing from not investing. In real options analysis, the investment is a “now-or-never” decision only at expiration. We can use two maximization functions to express this idea of determining the values of C_u and C_d:

$$C_u = max\ \{0, uV_0 - X\} \tag{3.5}$$

$$C_d = max\ \{0, dV_0 - X\} \tag{3.6}$$

Plugging the values of C_u and C_d into equation 3.5 and 3.6, we can obtain the solutions for m and B:

$$m = \frac{C_u - C_d}{(u-d)V_0} \tag{3.7}$$

$$B = \frac{uC_d - dC_u}{(u-d)(1+r_f)} \tag{3.8}$$

Substituting m and B in $C_0 = mV_0 + B$ with the above equations, we have the initial option value given by

$$C_0 = \frac{C_u - C_d}{(u-d)V_0} V_0 + \frac{uC_d - dC_u}{(u-d)(1+r_f)} \tag{3.9}$$

Or

$$C_0 = \frac{1}{(1+r_f)} \left[\frac{(1+r_f) - d}{u-d} C_u + \frac{u - (1+r_f)}{u-d} C_d \right] \tag{3.10}$$

From equation 3.10, we find that the option value C_0 is not affected by the objective probabilities q and 1- q. However, the value of q can be determined by the risk-adjusted rate of return r_a on the asset value V:

$$V_0 = \frac{qV_u + (1-q)V_d}{1+r_a} \tag{3.11}$$

Solving for q:

$$q = \frac{(1+r_a)V_0 - V_d}{V_u - V_d} \tag{3.12}$$

Because $V_u = uV_0$ and $V_d = dV_0$, equation 3.12 can be rewritten as

$$q = \frac{(1+r_a)-d}{u-d} \tag{3.13}$$

According to equation 3.13, we only need to know the value of the risk-adjusted rate of return r_a and the up and down factors to determine the value of the objective probabilities q and 1- q.

One-period binomial option pricing is only a special case with n = 1. However, for multi-period binomial option pricing, we can generalize the result beyond one-period binomial option pricing model. Let us simply assume that $Dt = T/n = 1$. Then the period i = 0, 1, 2, …, T and the option value at expiration $i = T$ is determined by the maximization function:

$$C_i = Max\{0, V_i - X\} \quad \text{for } i = T \tag{3.14}$$

If we let R_f denote the risk-free rate of return, i.e., $R_f = 1 + r_f$, then at period i = 0, 1, 2, …, T – 1, the option values are determined by

$$C_i = Max\left\{R_f^{-1}\left(\frac{R_f - d}{u-d}C_{i+1,u} + \frac{u - R_f}{u-d}C_{i+1,d}\right), V_i - X\right\} \qquad \text{for } i = 0, 1, \ldots, T\text{-}1 \tag{3.15}$$

Because the investor can exercise the option before expiration, one will need to compare

(1) the profits of investing at period ***i***, which is $V_i - X$ and (2) the option value at period ***i***, which is $R_f^{-1}\left(\frac{R_f - d}{u-d}C_{i+1,u} + \frac{u-R_f}{u-d}C_{i+1,d}\right)$. This is also referred to as the expected present value of the option of waiting until period ***i*** + 1 in the risk-neutral probability approach.

3.2 Risk-neutral Probability Approach

The risk-neutral probability approach (RNA) is based on the assumption that there exists an interest rate in the market that is risk-free, and that all individual investors are risk-neutral. In other words, individuals do not require compensation for risks (Hull, 2007). RNA assumes that the value of underlying asset before expiration will either go up by an up-factor ***u*** or go down by a down-factor ***d*** for each period. Correspondingly, the option value for each outcome of asset value will either go up or go down by risk-neutral probabilities. These probabilities are calculated by using the risk-free interest rate. Actually, if we let

$$p_u = p = \frac{R_f - d}{u-d} \tag{3.16}$$

and

$$p_d = 1 - p = \frac{u - R_f}{u-d} \tag{3.17}$$

Then equation 3.15 can be rewritten as

$$C_i = Max\left\{R_f^{-1}(p_u C_{i+1,u} + p_d C_{i+1,d}), V_i - X\right\} \text{ For } \boldsymbol{i} = 0, 1, \ldots, T\text{-}1 \tag{3.18}$$

Here, p_u and p_d are called the risk-neutral probabilities. Since equation 3.16 can be rewritten as

$$p_u = p = \frac{(1 + r_f) - d}{u - d} \tag{3.19}$$

Then, if we revisit equation 3.13 and compare it with equation 3.19, we can find that the risk-neutral probability p is equal to the objective probability q when we set the risk-adjusted rate of return r_a equal to risk-free rate of return r_f. The calculations for u and d are the same for the replicating portfolio approach as given in equations 3.1 and 3.2.

Therefore, the risk-neutral probability approach is similar to the replicating portfolio approach in terms of calculation; they are just different in the assumptions for rate of return. The assumption of risk-neutral interest rate eliminates the calculation of the risk-adjusted interest rate, as mentioned in the previous section for the replicating portfolio approach. The expression $R_f^{-1}(p_u C_{i+1,u} + p_d C_{i+1,d})$ in equation 3.18 can also be interpreted as the expected present value of waiting until period i + 1. The expression $V_i - X$ in equation 3.18 is the NPV from investing at current period i, where V_i is the present value (PV) of the cash flow and X is the initial investment. For $i = 0, 1, \ldots, T - 1$, if the value of waiting till next period exceeds the NPV of investing in the current period, i.e., $R_f^{-1}(p_u C_{i+1,u} + p_d C_{i+1,d}) > V_i - X$, then the option value C_i is equal to the value of waiting; otherwise, the option value C_i is equal to the profit of investing at current period, $V_i - X$. Let us summarize the risk-neutral probability approach:

$$C_i = Max\{0, V_i - X\} \quad \text{for } i = T \tag{3.20}$$

$$C_i = Max\left\{R_f^{-1}(p_u C_{i+1,u} + p_d C_{i+1,d}), V_i - X\right\} \text{ for } i = 0, 1, \ldots, T\text{-1} \tag{3.21}$$

For an option to start a project, the multi-period binomial tree of option values is given in Figure 3.2.

To decide the strategy at each node of the tree with different option values for period before expiration, that is, when $i < T$, we can use the criteria listed below:

(1) If $V_i - X > 0$, which means the NPV is positive and the strategy is to invest in period *i*;

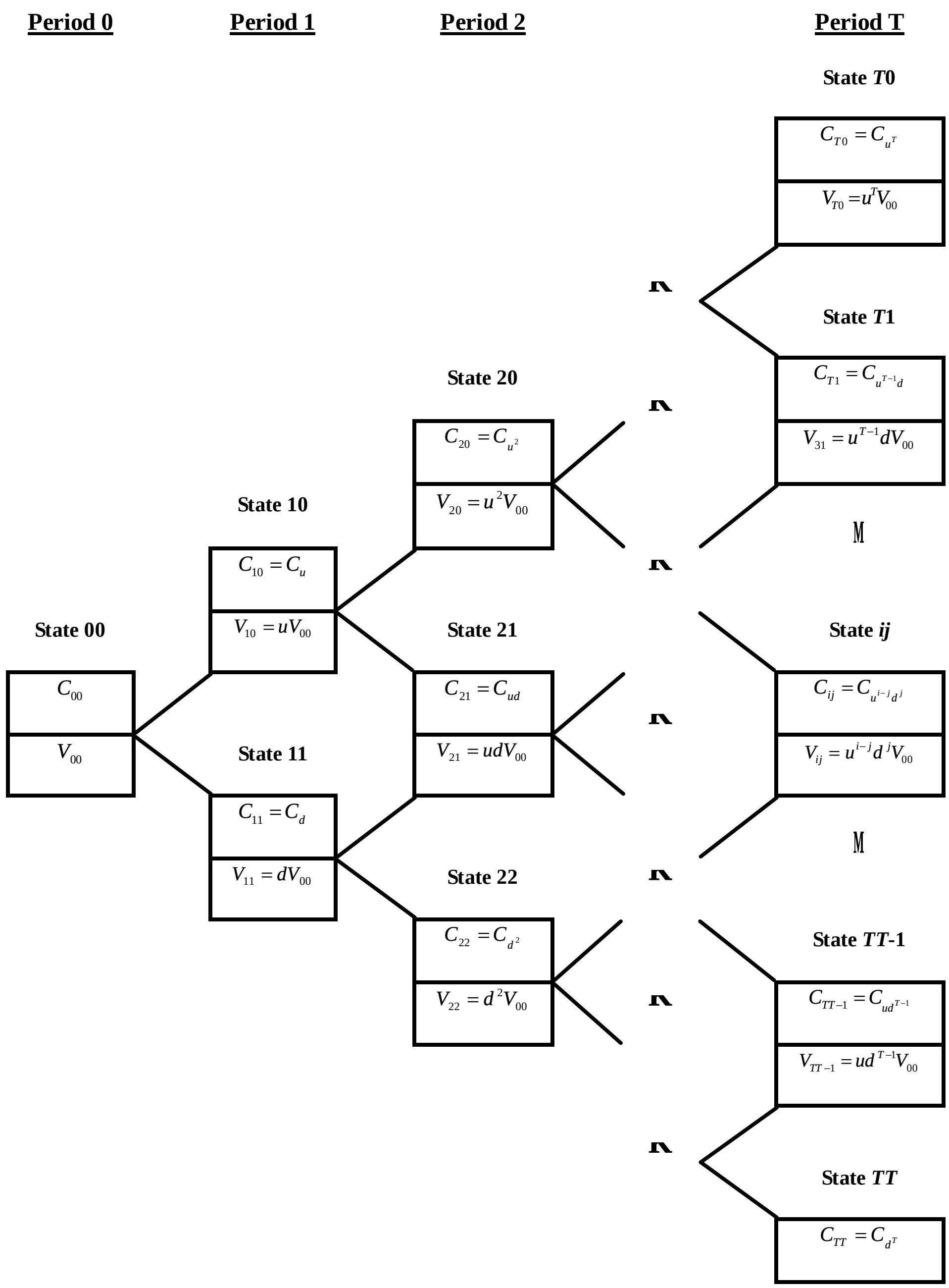
(2) If $R_f^{-1}(p_u C_{i+1,u} + p_d C_{i+1,d}) > 0 > V_i - X$, which means the value of waiting is larger than zero while the NPV is smaller than zero and the strategy is exercise the option to wait in period *i*;

(3) If $Max\{R_f^{-1}(p_u C_{i+1,u} + p_d C_{i+1,d}), V_i - X\} = 0$, that is, the maximum between value of waiting and NPV is zero, then the strategy is to reject the option to invest in period *i*.

At expiration, that is, when $i = T$, we use the NPV criteria to determine our strategies:

(4) If $V_i - X > 0$, which means the NPV is positive, then the strategy is to invest in period *i*;

Figure 3.2 Binomial Tree of Option Values



(5) If $V_i - X < 0$, which means the NPV is negative, then the strategy is to reject the investment in period *i*.

Although the evaluation of real options to start is similar to the evaluation of American call options in the financial market, the strategies are different. Usually for American options, the investor can choose to exercise earlier only when the profits from exercising is larger than the value of waiting, i.e., when $V_i - X > R_f^{-1}(p_u C_{i+1,u} + p_d C_{i+1,d})$. Even if the NPV ($V_i - X$) is greater than zero, the investor is suggested to wait if the inequality $R_f^{-1}(p_u C_{i+1,u} + p_d C_{i+1,d}) > V_i - X$ holds. In our real options analysis, we derive different strategies with the criteria above. The investor is suggested to invest as long as $V_i - X$ is larger than zero, even if the value of waiting $R_f^{-1}(p_u C_{i+1,u} + p_d C_{i+1,d})$ exceeds the NPV of investing. This is because if an investor chooses to wait when $R_f^{-1}(p_u C_{i+1,u} + p_d C_{i+1,d})$ $> V_i - X$ holds, it only makes the investment more profitable. It is not necessary for the investor to wait if she thinks the profit made by investing for current period is considerable.

Chapter 4 Calibration of the Simulation Model

In our evaluation of investment decisions in ethanol facilities, we will use the risk-neutral probability approach (RNA) to calibrate the model to ethanol asset. There are two reasons of using RNA instead of replicating portfolio approach (RPA): first, it is easier to determine the risk-free rate of return than to determine the risk-adjusted rate of return on a specific asset. Historical information for risk-free interest rates is available from financial market. In practice, people usually use interest rates on short-term US treasury bills to risk-free interest rates, such as three-month US Treasury Bills. The interest rates on short-term US Treasury Bills are expected to carry the lowest risk in the real world. This is why these are usually chosen when researchers need to use a risk-free interest rate.

Second, the assumption of a twin asset in RPA suits better for financial options than for real options. However, it is usually difficult to determine how the twin asset (or replicating portfolio) should be formulated. This is because financial options are options on standardized commodities or instruments that are traded in financial markets. The market prices of the underlying asset, such as a stock, a currency, a stock index, or a futures contract, are detectable from the market. For example, for a futures option, the value of the underlying asset V_0 in equation 3.3 and 3.4 is just the price of the underlying futures traded in the financial market. However, for most real assets, there are no marketed prices since they are not traded as financial assets.

Based on the RNA, we will interpret how the parameters in the model are defined and calculated in calibrating the model to the ethanol plant asset. These parameters include the volatility σ and the risk-free interest rate r_f. Then, we will discuss how other parameters in BOPM are derived, including the up-factor u, the down-factor d, the up-probability p_u, and the down-probability p_d. The historical data used for calculating the parameters and the plant-level data for analyzing the investment option values will also be introduced.

4.1 Volatility

Volatility is a measure of the uncertainty of the return realized on an asset (Hull, 2007). In our empirical model, the return is set equal to the present value (PV) of the ethanol asset[4]. Volatility reflects the uncertainty of future cash flows. With higher volatility, the investor may expect higher variation of the change in return and higher risk will be carried by the asset. With lower volatility, on the other hand, an investor may expect lower variation and lower risk of the return on asset.

The definition of volatility is derived from the Geometric Brownian Motion (Dixit and Pindyck, 1994). Assume that the value of the ethanol asset V is a random variable and it follows the stochastic process of GBM. Then the instantaneous change in the asset return $\frac{dV}{V}$ can be written in the following equation

[4] More on the definition and calculation of asset value will be introduced in chapter 5.

$$\frac{dV}{V} = a\,dt + s\,dz \qquad (4.1)$$

In equation 4.1, α is the growth rate of *V* over time and is also the “drift” parameter; σ is the standard deviation of the change of *V* and is the variation or “diffusion” parameter, which is also the volatility in our discussion; ***dt*** is the incremental change in time *t*; and ***dz*** is the standard Wiener process such that

$$dz = e_t \sqrt{dt} \qquad (4.2)$$

where ε_t is a random variable with expectation equal zero and variance equal one. Therefore, the expectation of ***dz*** is also zero.

However, GMB is only the continuous version for the stochastic process of variable *V*. We may also use a discrete approach, substituting *Dt* instead of ***dt*** to denote the discrete change of time. As introduced in Chapter 3, the discrete method that will be used in our analysis is the binomial option pricing model (BOPM). The definition of volatility σ is the same for either the continuous model or the discrete model.

We will use Monte Carlo simulation (MCS) to generate cash flows (CFs) and calculate the corresponding PVs of the ethanol asset. There are three different types of combustion technologies for corn-based dry-milling ethanol plant, the conventional technology is using natural gas for combustion, the other two alternatives are using corn stover and a combination of corn stover and syrup for combustion. In estimating CFs, ethanol price, corn price, and fuel price are variables. For conventional technology, historical prices of ethanol, corn, and natural gas will be used in the estimation. For the other two alternatives, because historical price of corn stover is not available, we will use the distribution assumption for corn stover price by Petrolia (2006) and simulate historical price series for stover. Other prices, costs, and efficiency ratios in the estimations are assumed to be constant, based on historical average and assumptions from related studies. The PV of the ethanol asset is the asset price that will be used in the binomial option pricing model. The expected volatility of PV will be estimated by Black-Scholes-Merton's (BSM) method and the introduction to BSM method is given in Appendix B.

4.1.1 The Volatility of Present Value for a Conventional Plant

In our study, a conventional ethanol plant is assumed to use natural gas as the combustion fuel. It is also referred to as "conventional plant" or simply "conventional" in later text. To estimate the volatility of the conventional ethanol asset value, we collect the historical monthly data for ethanol price, corn price and natural gas price from January 1, 2001 to August 1, 2007. There are 80 observations for each of these three variables. To calculate the CFs for the 80 months, we assume that the conventional plant has a constant production capacity of 50 million gallons per year (mm gpy) and all other costs and prices are also constant. Consequently, the monthly production is also constant, which equals 4.17 million gallons. Thus, the production level is constant and the volatility value (by BSM method) will not be affected by the quantity of production. Therefore, the volatility of CF per gallon of ethanol (CFG) is a function of marketed price volatility.

The summary of the other constant prices and costs are given in Appendix A.

The estimated CFs and simulated PVs are in unit of per gallon of ethanol production. To calculate historical CFs, we use the following equation:

$$\text{CF} = \text{EBITDA} - \text{Interest Expense} - \text{Income Tax} \quad (4.3)$$ [5]

In equation 4.3, EBITDA is the earnings before interest, tax, depreciation and amortization. EBITDA is calculated by

$$\text{EBITDA} = \text{Total Revenue} - \text{Total COGS} - \text{Total Operating Expenses} \quad (4.4)$$

where COGS denotes the costs of goods sold. We assume that for a conventional plant, the Total Revenue is from sales of ethanol and dried distiller grains (DDGS), and the Total COGS include corn cost, natural gas cost, electricity cost, denaturant cost, costs for chemicals, enzymes, and yeasts, and costs for water and waste. The values and description for these revenue and cost items are given in Appendix A. Substituting EBITDA in (4.3) with (4.4), we get

$$\begin{aligned}\text{CF} = {} & \text{Total Revenue} - \text{Total COGS} - \text{Total Operating Expenses} - \text{Interest Expense} \\ & - \text{Income Tax}\end{aligned}$$

Or

[5] The income tax rate for all types of ethanol plants in the study is assumed to be zero, since in practice most of the ethanol plants are limited liability companies and no income tax are imposed.

CF = Ethanol Sales + DDGS Sales – Corn Cost – Natural Gas Cost – Total Other COGS – Total Operating Expenses – Interest Expenses (4.5)

When calculating CF, the ethanol price, corn price, and natural gas price are assumed to be variables while all other COGS, operating expenses, and interest expenses are assumed to be constants. So we can integrate all the COGS and expenses items together except for the corn cost and natural gas cost. Let $\overline{C}_{O-C}$ denote the integrated other COGS and expenses, and let CF_C denote the cash flows for the conventional plant. Then equation 4.5 can be rewritten as

$$CF\_C = (\tilde{P}_E \overline{Q}_E + \overline{P}_D \overline{Q}_{D-C}) - (\tilde{P}_C \overline{Q}_C + \tilde{P}_N \overline{Q}_N) - \overline{C}_{O-C}$$

The values and descriptions of variables in the above equation are given in Table 4.1. Divide both sides by the quantity of ethanol production, $\overline{Q}_E$, we have the equation for calculating CFG_C, the cash flows per gallon for a conventional plant:

$$CFG\_C = \frac{CF\_C}{\overline{Q}_E} = (\tilde{P}_E + \overline{P}_D \frac{\overline{Q}_{D-C}}{\overline{Q}_E}) - (\tilde{P}_C \frac{\overline{Q}_C}{\overline{Q}_E} + \tilde{P}_N \frac{\overline{Q}_{N-C}}{\overline{Q}_E}) - \frac{\overline{C}_{O-C}}{\overline{Q}_E}$$

Or

$$CFG\_C = (\tilde{P}_E + \overline{P}_D \overline{q}_{D-C}) - (\tilde{P}_C \overline{q}_C + \tilde{P}_N \overline{q}_N) - \overline{c}_{O-C} \qquad (4.6)$$

Table 4.1 Description of Variables (Conventional)*

Notation	Value	Description	Unit
$\tilde{P}_E$	Variable	Ethanol price	$/gallon
$\tilde{P}_C$	Variable	Corn price	$/bushel
$\tilde{P}_N$	Variable	Natural gas price	$/mmbtu
$\overline{P}_D$	92.85	Dried distiller grains (DDGS) price	$/ton
$\overline{q}_C = \frac{\overline{Q}_C}{\overline{Q}_E}$	0.3509	Corn use per gallon of ethanol	bushels/gallon
$\overline{q}_N = \frac{\overline{Q}_N}{\overline{Q}_E}$	0.0350	Natural gas use per gallon of ethanol, conventional	mmbtus/gallon
$\overline{q}_{D-C} = \frac{\overline{Q}_{D-C}}{\overline{Q}_E}$	0.0032	DDGS production per gallon of ethanol, conventional	bushels/gallon
$\overline{c}_{O-C} = \frac{\overline{C}_{O-C}}{\overline{Q}_E}$	0.3671	Other costs per gallon of ethanol, conventional	$/gallon

* See Appendix A for table of efficiency ratios, production and consumption items and the source of data.

From the data given in Table A.1, we know that $\overline{c}_{O-C}$ is calculated by

$$\overline{c}_{O-C} = \overline{P}_{El}\,\overline{q}_{El} + \overline{P}_{De}\,\overline{q}_{De} + \overline{c}_{Ch} + \overline{c}_{Wa} + \overline{c}_{OE} + \overline{c}_{IE-C}$$

$$= 0.05(0.75) + 1.50(0.05) + 0.06 + 0.005 + 0.15 + 0.0396$$

$$= 0.3671$$

Therefore, equation 4.6 can be rewritten as

$$CFG\_C = \tilde{P}_E + 92.85(0.0032) - 0.3509\tilde{P}_C - 0.0350\tilde{P}_N - 0.3671$$

That is,

$$CFG\_C = \tilde{P}_E - 0.3509\tilde{P}_C - 0.0350\tilde{P}_N - 0.0700 \qquad (4.7)$$

Equation 4.7 is used to calculate the monthly CFG_C. Selected number of observations for the historical monthly prices and the calculated CFG_C are given in Table A.2. Using @Risk software, we can fit a normal distribution to CFG_C, with mean equal to 0.59 and standard deviation equal to 0.50. That is, we can assume that

$$CFG\_C \sim \text{Normal}\ (0.59,\ 0.50^2) \qquad (4.8)$$

The plot of CFG_C is given in Figure 4.1 and the fitted normal distribution to CFG is given in Figure 4.2.

Figure 4.1 Estimated conventional CFG_C, 1/1/2001- 8/1/2007

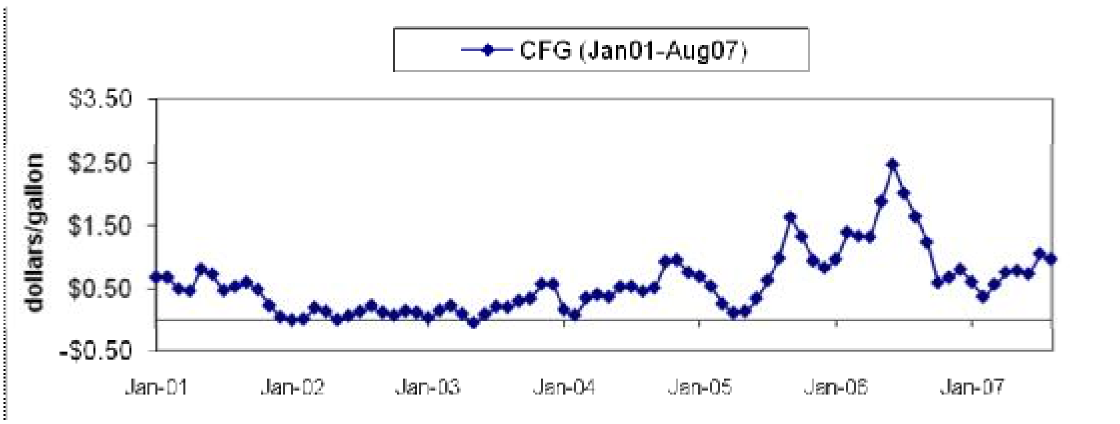
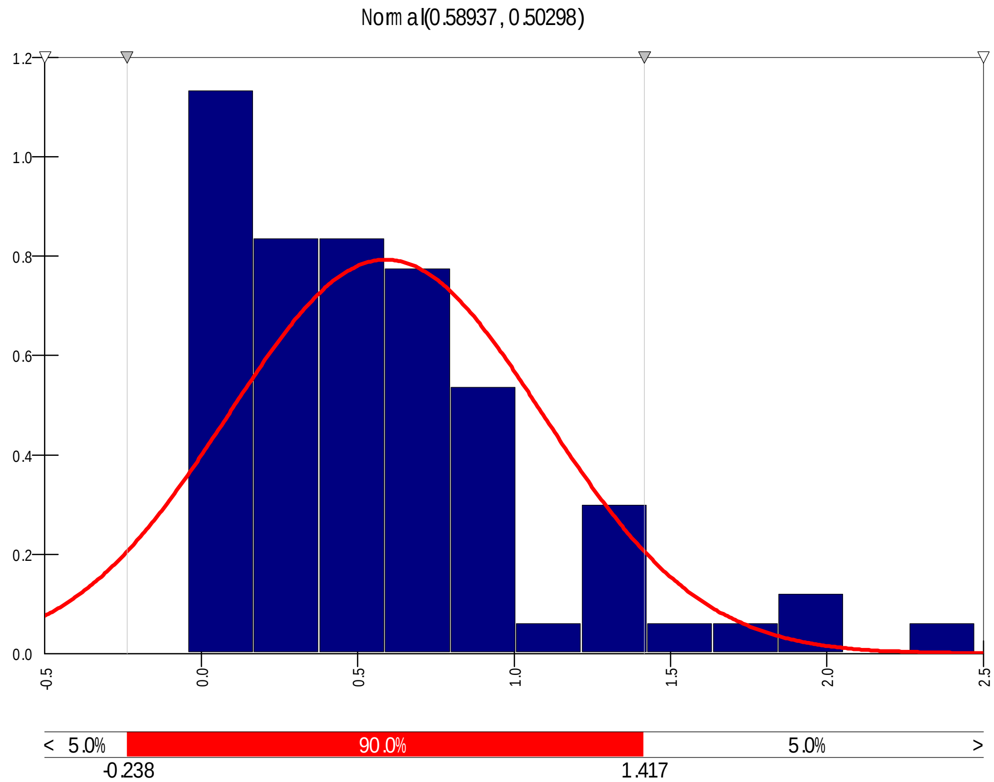


Figure 4.2 Fitted Distribution to CFG_C, 1/1/2001-8/1/2007



Generally, we assume that there are 15 years for the plant to be in operation, and the expected CFG in each year will follow a fitted distribution such as 4.8. The expected present value per gallon of ethanol PVG of a plant is the sum of discounted expected CFG and expected disposal cash flows DCFG:

$$E(PVG) = \sum_{i=0}^{S} \frac{E(CFG_i)}{(1+r_f)^i} + \frac{E(DCFG)}{(1+r_f)^S} \qquad (4.9)$$

In equation 4.9, r_f is the risk-free rate of return, which equals 0.04.[6] We assume E(DCFG) after 15 years of operation to be 15% of the construction cost[7], which equals $0.3375/gallon for the conventional plant. *S* is the life time of the project or the asset, for estimating the volatility of PVG in this chapter, S equals 15 for all types of plants. For the expected CFG_C in each year we draw 500 random values from (4.8) and in this way, a 500x15 matrix is formed and we can have 500 calculations of the PVG_C, the present value per gallon for a conventional plant. Table 4.2 gives the first 10 rows of the simulated CFG_C random sample and calculations of PVG_C of the matrix. In this table, $Ln(PVG_i / PVG_{i-1})$ is the logarithm of change in PVG. By BSM method, the standard deviation of $Ln(PVG_i / PVG_{i-1})$ is just the volatility of PVG. For example, the present value of the CFG_C in observation 1 (OBS 1) in the first row of the matrix is $9.13. It is calculated by

$$\sum_{i=1}^{15} \frac{E(CFG_i)}{(1+r_f)^i} + \frac{DCFG}{(1+r_f)^{15}}$$

$$= (\frac{\$0.27}{1.04^1} + \frac{\$0.03}{1.04^2} + \frac{\$0.32}{1.04^3} + \frac{\$0.78}{1.04^4} + \frac{\$1.15}{1.04^5} + \frac{\$0.57}{1.04^6} + \frac{\$1.40}{1.04^7} + \frac{\$1.03}{1.04^8} + \frac{\$1.09}{1.04^9} + \frac{\$1.03}{1.04^{10}} + \frac{\$0.35}{1.04^{11}}$$
$$+ \frac{\$0.84}{1.04^{12}} + \frac{\$1.48}{1.04^{13}} + \frac{\$1.80}{1.04^{14}} + \frac{\$0.62}{1.04^{15}}) + \frac{\$0.34}{1.04^{15}}$$

$$= \$9.13$$

[6] The estimation of risk-free interest rate will be introduced in section 4.2. For all types of plants, we assume the same risk-free rate of return.
[7] The assumption for construction costs for all types of plants are given in Appendix 4.2. We assume DCFG to be 15% of the construction costs for any type of plants.

Table 4.2 Simulated CFG and PVG, first 10 Simulations and Calculations from (4.7)

(Unit: per gallon of ethanol)

OBS	PVG	$\ln \frac{PVG_i}{PVG_{i-1}}$	CFG														
			Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
1	$9.13		$0.27	$0.03	$0.32	$0.78	$1.15	$0.57	$1.40	$1.03	$1.09	$1.03	$0.35	$0.84	$1.48	$1.80	$0.62
2	$7.83	(0.15)	$1.15	$1.14	$0.59	($0.05)	$0.25	$0.10	$0.74	$1.31	$0.43	$0.63	$0.10	$1.27	$1.00	$0.56	$1.24
3	$7.12	(0.10)	$0.62	$1.44	$0.51	($0.47)	$0.14	$1.64	$0.01	$1.10	$0.63	$1.20	$0.59	$0.97	($0.01)	$0.21	$0.70
4	$6.29	(0.12)	$0.35	$0.68	$0.55	$1.11	$0.15	$0.17	($0.10)	$0.02	$1.53	$1.42	$1.00	$0.32	$0.18	$0.51	$0.39
5	$6.18	(0.02)	$0.44	$0.55	$0.95	$0.29	$1.07	$0.59	$0.82	($0.10)	$1.08	($0.22)	$0.93	$0.41	$0.29	$0.20	$0.56
6	$8.62	0.33	$0.94	$1.35	$0.58	$1.09	$0.43	$0.41	($0.02)	$1.18	$0.72	$1.16	$0.56	$0.92	$0.90	$0.21	$0.75
7	$4.96	(0.55)	$0.36	$0.60	$0.34	$0.32	$0.09	$0.37	$0.29	$0.99	$0.34	$0.49	$0.43	$0.35	$1.07	$0.01	$0.47
8	$6.15	0.22	$0.82	$1.09	($0.17)	$0.54	$1.00	$0.11	$0.79	$0.36	$0.36	$1.41	$0.26	$1.39	$0.60	($0.69)	($0.22)
9	$7.35	0.18	$0.01	$2.28	$0.71	$0.06	$0.39	$1.27	$0.84	$0.66	($0.68)	$1.00	$0.13	$0.33	$1.04	$0.82	$0.60
10	$8.32	0.12	$0.95	$1.00	$0.89	$0.81	$0.37	$0.28	$1.28	$0.45	$0.65	$1.40	$0.29	$0.96	$0.26	$1.02	$0.10

Table 4.3 Matrix of Simulated Cash Flows and Present Values

OBS #	PVG_i	$u_i = \ln \frac{PVG_i}{PVG_{i-1}}$	CFG (Year1)	CFG (Year2)	CFG (Year3)	$\cdots$	CFG (Year14)	CFG (Year15)
1	PVG_1		CFG_{11}	CFG_{21}	CFG_{31}		CFG_{141}	CFG_{151}
2	PVG_2	u_1	CFG_{12}	CFG_{22}	CFG_{32}	$\cdots$	CFG_{142}	CFG_{152}
3	PVG_3	u_2	CFG_{13}	CFG_{23}	CFG_{33}		CFG_{143}	CFG_{153}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$
498	PVG_{498}	u_{497}	CFG_{1498}	CFG_{2498}	CFG_{3498}		CFG_{14498}	CFG_{15498}
499	PVG_{499}	u_{498}	CFG_{1499}	CFG_{2499}	CFG_{3499}	$\cdots$	CFG_{14499}	CFG_{15499}
500	PVG_{500}	u_{499}	CFG_{1500}	CFG_{2500}	CFG_{3500}	$\cdots$	CFG_{14500}	CFG_{15500}

A generalized matrix for the simulation of CFG in each year and the calculation for PVG is given by Table 4.3. In @Risk, we can just set $u_i = Ln(PVG_i / PVG_{i-1})$ as an output and run the simulation. Then @Risk will report the standard deviation of this output, which is just the volatility of PVG for the conventional plant. The reported volatility of PVG_C is 33.13%.

We observe in Figure 4.1 that the CFG exhibits different patterns for different sub periods during the whole period. That is, after January 2005, the CFG seems to have higher variation and fluctuate more violently. So what if the history in this period is to replay in the future? To recapture the price uncertainty in different periods in the history, we set the CFG in May 2002 to December 2004 as Subperiod I and the CFG in January 2005 to August 2007 as Subperiod II. We do not include the historical data before May 2002 to make the two sub periods comparable in sample size. So both Subperiod I and Subperiod II are having 32 observations of CFG. By @Risk, Subperiod I follows a normal distribution with mean equal to 0.31 and standard deviation equal to 0.26:

$$\text{CFG\_C}_1 \sim \text{Normal}\ (0.31, 0.26^2) \qquad (4.10)$$

and Subperiod II follows a normal distribution with mean equal to 0.96 and standard deviation equal to 0.55:

$$\text{CFG\_C}_2 \sim \text{Normal}\ (0.96, 0.55^2) \qquad (4.11)$$

The fitted normal distributions to CFG_C_1 and CFG_C_2 are given in Figure 4.4 and 4.5, respectively.

Similarly as we do for the CFG of the whole sample (January 2001 to August 2007, 80 observations), we can use (4.9) and let @Risk do the simulation (as in Table 4.3) with the fitted distributions 4.10 and 4.11, respectively. The reported volatility of PVG when assuming CFG_C_1 is 31.42% and that when assuming CFG_C_2 is 21.52%

Figure 4.3 Fitted Distribution to CFG_C1, 5/1/2002-12/1/2004

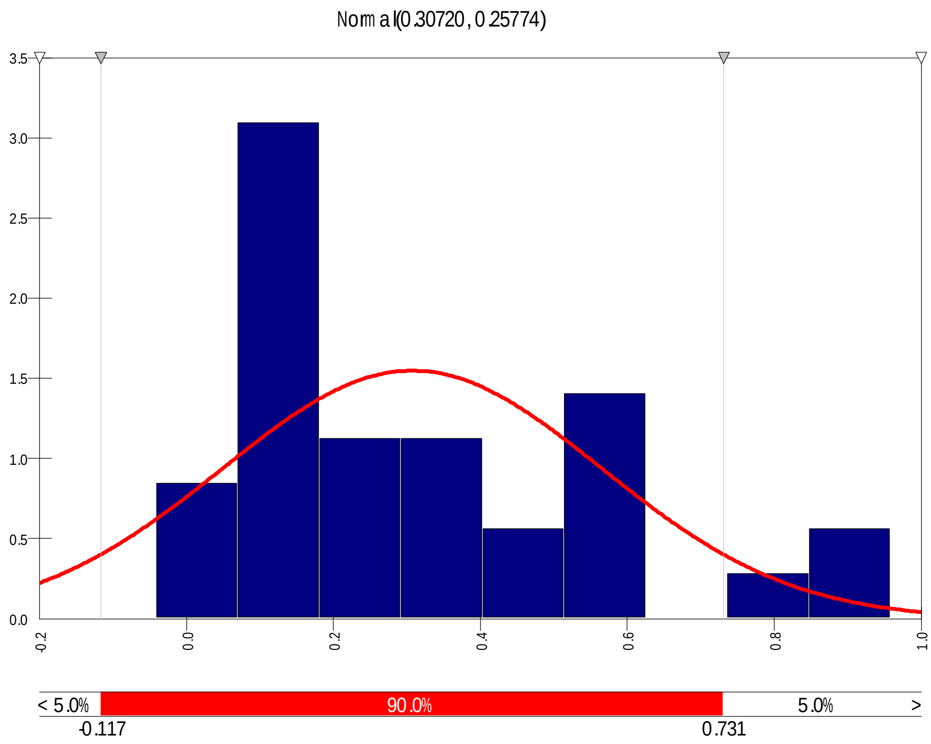
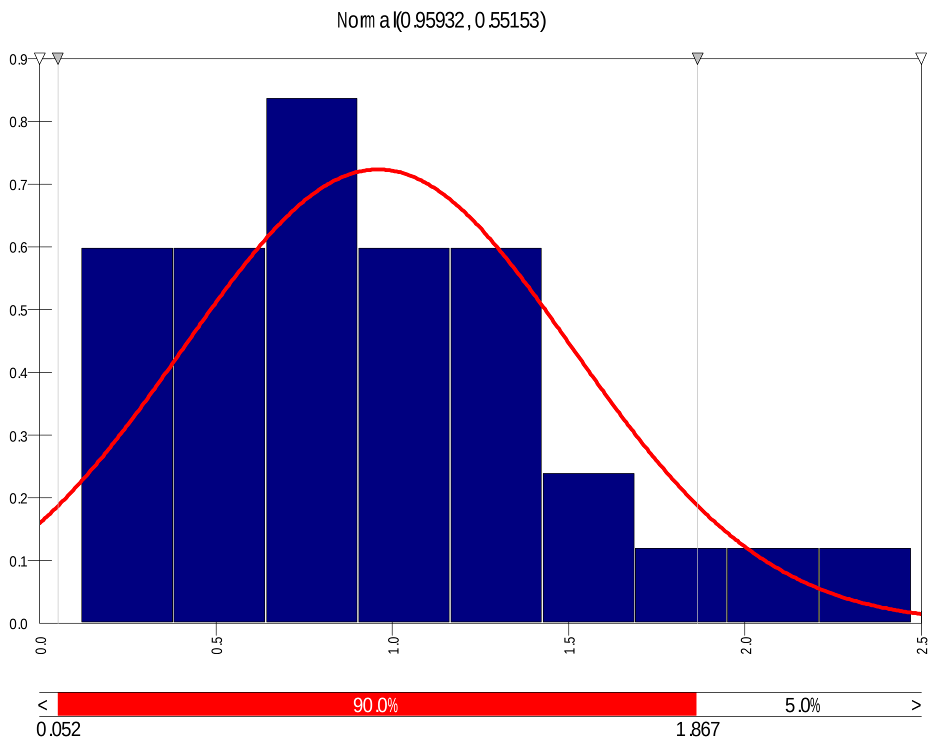


Figure 4.4 Fitted Distribution to CFG_C2, 1/1/2005-8/1/2007



4.1.2 The Volatility of Present Value for a Stover Plant

Due to the increasing price of natural gas, new combustion technology has been developed to reduce energy cost of dry-milling ethanol plant. Corn stover is one of the alternative biomass boiler fuels that make lower energy costs for ethanol investors. The stover combustion will be referred to as “stover combustion” or simply “stover” in this paper. From the study by Kam et al. in 2007, for stover combustion in dry-milling ethanol plant, the construction cost is estimated at $2.94 per gallon of denatured ethanol production. The costs of goods sold (COGS) include the cost of buying corn stover at $80 per ton and ammonia for nitrogen control at $500 per ton. For a plant with 50 million gallons capacity, the corn stover consumption is estimated to be 132, 046 tons (0.0026 tons per gallon of ethanol production) and the ammonia consumption is estimated to be 330 tons (0.00007 tons per gallon of ethanol production). The electricity consumption for a gallon of ethanol production is 0.20 (kwhs) higher for stover plant than for conventional plant. The interest expense and depreciation for stover combustion are also higher than those for a conventional ethanol plant with the same capacity. Compared to conventional ethanol plant, there is also additional revenue from a marketable byproduct, ash. Ash is sold as fertilizer at $200 per ton. The comparison of efficiency ratios, production and consumption items, other COGS, and expenses between conventional and alternative technologies are given in Table A.1.

Let CFG_S denote the variable of cash flows per gallon, and PVG_S denote the present value per gallon for a stover plant. To simulate the historical CFG_S values and calculate the volatility of PVG_S, we need to establish the model of CFG_S with the price variables, which is similar to equation 4.7. If we are expecting that stover will be the relevant energy source for a dry-milling ethanol plant in the future, we need assume that the corn stover price will be varying rather than being constant in the equation. In this way, we can incorporate the volatility of stover price to the volatility of CFG_S and PVG_S. Petrolia (2006) studied the cost of harvesting and transporting corn stover for a biomass ethanol plant, and the corn stover cost is estimated to follow a lognormal distribution[8] by Monte Carlo simulation (MCS). The mean of the corn stover cost is $52.00 and the standard deviation is $11.00. @Risk uses the mean and standard deviation of the variable directly to define a lognormal distribution, but not the mean and standard deviation of the logged variable. So the lognormal distribution in @Risk is named RiskLognormal instead of lognormal[9]. However, we can achieve the same result using either definition. Therefore, we can define that the corn stover cost follows the RiskLognormal distribution

$$\tilde{P}_S \sim \text{RiskLognormal}(52,\ 11,\ \text{RiskTruncate}(40{,}80)) \qquad (4.12)$$

The RiskTruncate parameter defines the range of the simulated value from distribution 4.11. That is, the minimum of the values simulated from (4.12) will not be smaller than 40 and the maximum will not be larger than 80. We use the same period of historical data for ethanol price and corn price, which is from January 2001 to August 2007. We will

[8] By Petrolia (2006), it is a visual inspection of the probability distributions of corn stover costs. The data were transformed into natural logarithms and replotted, which revealed normal distributions. The parameters of the lognormal distribution were not reported.
[9] See Appendix 4.5 for the difference between RiskLognormal distribution and Lognormal distribution.

assume that the stover price follows (4.12) and draw 80 random values from this distribution to match the length of historical data for ethanol and corn prices. For a stover plant, the model of cash flows per gallon is given by

$$CFG\_S = (\tilde{P}_E + \overline{P}_D \overline{q}_{D-S} + \overline{P}_A \overline{q}_{A-S}) - (\tilde{P}_C \overline{q}_C + \tilde{P}_S \overline{q}_{S-S}) - \overline{c}_{O-S} \qquad (4.13)$$

We assume that the revenues per gallon of the stover plant are from ethanol sales per gallon $\tilde{P}_E$ (which is just the ethanol price), DDGS sales per gallon $\overline{P}_D \overline{q}_{D-S}$, and ash sales per gallon $\overline{P}_A \overline{q}_{A-S}$. The main costs are from corn cost $\tilde{P}_C \overline{q}_C$ and stover cost $\tilde{P}_S \overline{q}_{S-S}$. All other COGS and expenses is denoted by $\overline{c}_{O-S}$. The descriptions and values of the variables in (4.13) are given in Table 4.4.

Table 4.4 Descriptions of Variables (Stover)*

Notation	Value	Description	Unit
$\tilde{P}_E$	Variable	Ethanol price	$/gallon
$\tilde{P}_C$	Variable	Corn price	$/bushel
$\tilde{P}_S$	Variable	Corn stover price	$/ton
$\overline{P}_D$	92.85	Dried distiller grains (DDGS) price	$/ton
$\overline{P}_A$	200.00	Ash price	$/ton
$\overline{q}_{S-S} = \frac{\overline{Q}_{S-S}}{\overline{Q}_E}$	0.0026	Stover use per gallon of ethanol, stover	tons/gallon
$\overline{q}_{D-S} = \frac{\overline{Q}_{D-S}}{\overline{Q}_E}$	0.0032	DDGS production per gallon of ethanol, stover	bushels/gallon
$\overline{q}_{A-S} = \frac{\overline{Q}_{A-S}}{\overline{Q}_E}$	0.00016	Ash production per gallon of ethanol, stover	tons/gallon
$\overline{c}_{O-S} = \frac{\overline{C}_{O-S}}{\overline{Q}_E}$	0.3927	Other costs per gallon of ethanol, stover	$/gallon

* See Appendix A for table of efficiency ratios, production and consumption items and the source of data.

Similar as the case of $\overline{c}_{O-C}$, we use the data given in Table A.1 and calculate the other costs per gallon for the stover plant:

$$\overline{c}_{O-S} = \overline{P}_{El}\,\overline{q}_{El} + \overline{P}_{De}\,\overline{q}_{De} + \overline{P}_{Am}\,\overline{q}_{Am-P} + \overline{c}_{Ch} + \overline{c}_{Wa} + \overline{c}_{OE} + \overline{c}_{IE-S}$$

$$= 0.05(0.95) + 1.50(0.05) + 500(0.000007) + 0.06 + 0.005 + 0.15 + 0.0517$$

$$= 0.3927$$

As mentioned previously, we can see that for the stover plant, the electricity cost $\overline{P}_{El}\,\overline{q}_{El}$ and the interest expense $\overline{c}_{IE-S}$ are higher than those for the conventional plant. There is also an additional cost for ammonia $\overline{P}_{Am}\,\overline{q}_{Am}$ for stover plant. From Table A.1, we know that the DDGS price $\overline{P}_D$ is $92.85/ton and the DDGS production per gallon $\overline{q}_{D-S}$ is 0.0032. These two items are the same for stover plant as for conventional plant. So equation 4.12

can be rewritten as

$$CFG\_S = \widetilde{P}_E + 92.85(0.0032) + 200.00(0.00016) - 0.3509\widetilde{P}_C - 0.0026\widetilde{P}_S - 0.3927$$

Or

$$CFG\_S = \widetilde{P}_E - 0.3509\widetilde{P}_C - 0.0026\widetilde{P}_S - 0.0636 \qquad (4.14)$$

An overview of the historical prices and calculations of CFG_S are given in Table A.2. Using @Risk, we can fit a normal distribution to the 80 calculations of CFG_S:

$$\text{CFG\_S} \sim \text{RiskNormal}(0.68,\ 0.55^2) \qquad (4.15)$$

The expectation of CFG_S by this distribution is $0.68/gallon, and the standard deviation of CFG_S is $0.55/gallon. The plot of simulated CFG_S is given in Figure 4.8 and the fit normal distribution to CFG_S is given in Figure 4.9. The DCFG for the stover plant is $0.4410. Using equation (4.9) and let @Risk do the simulation as illustrated in Table 4.3, we have the volatility of PVG_S reported as 30.84%.

Figure 4.5 Estimated CFG_S, 1/1/2001-8/1/2007

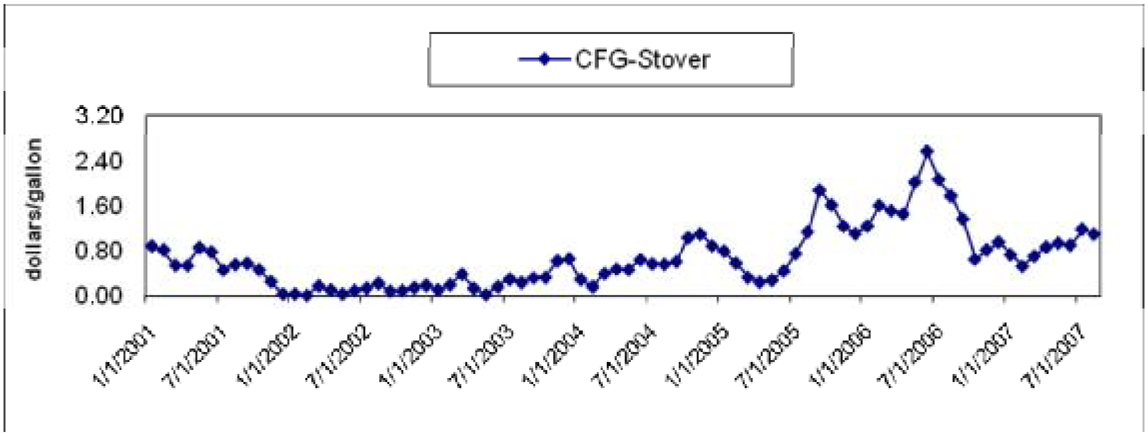
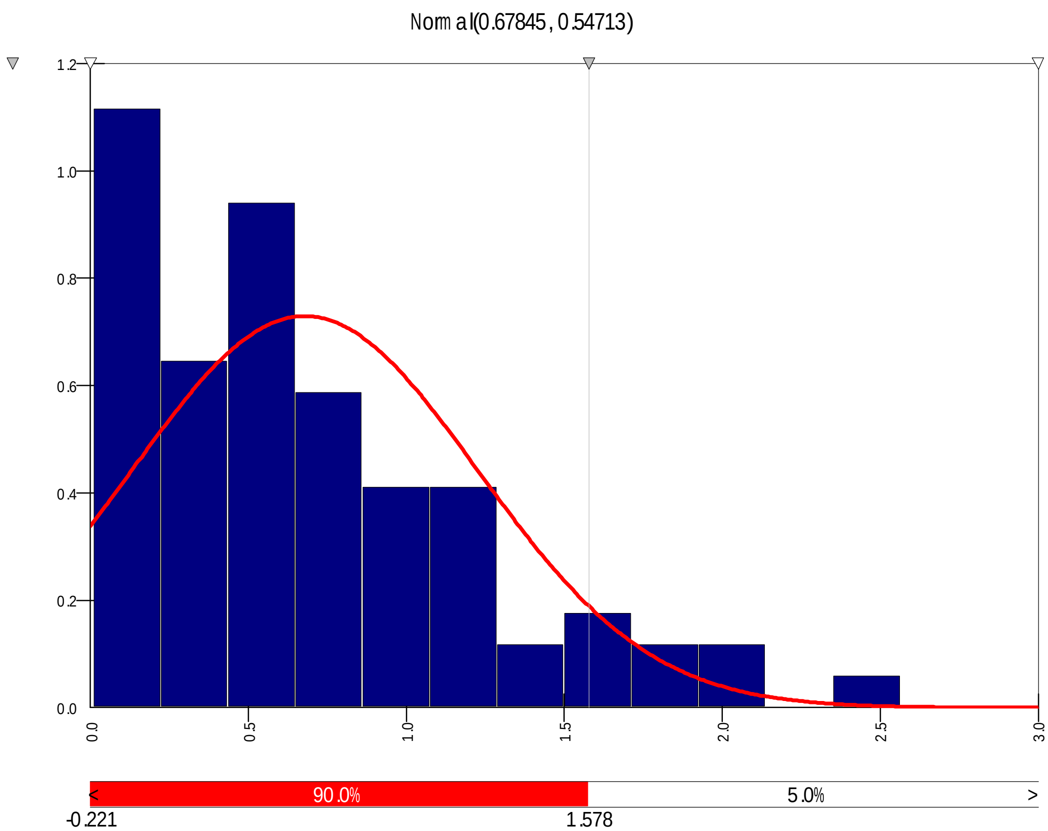


Figure 4.6 Fitted Normal Distribution to CFG_S, 1/1/2001-8/1/2007



4.1.3 The Volatility of Present Value for a Stover-plus Plant

As previously mentioned, for investors who are interested in biomass combustion for ethanol plants, there is another technology for boiler fuel. This is using corn stover and syrup together for combustion instead of natural gas. It is more economical that the investor does not need to buy the syrup. Extracted from the distiller's' grains, the syrup is actually a byproduct of producing ethanol. Combining the stover and syrup together, the consumption for stover is reduced and so is the total cost for stover. In the later text, we will refer to the stover plus syrup combustion technology simply as "stover-plus" or "stover+". From Table A.1 we can see that the construction cost is actually lower compared to the "stover only" combustion. This is because that the stover-plus technology requires a smaller tank to burn the mixture of biomass fuel. The interest expense is consequently lower, since the construction loan is lower. On the other hand, because the syrup is extracted from the distiller's' grains, the production of DDGS is less than that from conventional plant or stover plant. Lower ammonia is required for stover-plus plant because less nitrogen is emitted. There is an additional cost for limestone because it is needed for gasification of syrup in the incinerator. More illustrations are given in Table A.1 for comparing stover plant and stover-plus plant.

For the stover-plus plant, we assume that the revenues are from ethanol sales, DDGS sales, and ash sales, and the costs and expenses are from electricity cost, denaturant cost, ammonia cost, limestone cost, cost for chemicals, enzymes and yeast, cost for water and waste, operating expenses, and interest expense. Similarly as we did for calculating the

CFG of the conventional plant and the stover plant, we let CFG_P denote the cash flows per gallon for the stover-plus plant and it can be written as

$$CFG\_P = (\tilde{P}_E + \bar{P}_D \bar{q}_{D-P} + \bar{P}_A \bar{q}_{A-P}) - (\tilde{P}_C \bar{q}_C + \tilde{P}_S \bar{q}_{S-P}) - \bar{c}_{O-P} \quad (4.16)$$

From equation 4.17 we can see that the revenues per gallon in the first parenthesis is from ethanol sales per gallon (which is just the ethanol price in unit of $/gallon), DDGS sales per gallon $\bar{P}_D \bar{q}_{D-P}$, and ash sales per gallon $\bar{P}_A \bar{q}_{A-P}$. The main COGS include corn cost $\tilde{P}_C \bar{q}_C$ and stover cost $\tilde{P}_S \bar{q}_{S-P}$. All the other costs and expense are integrated by $\bar{c}_{O-P}$.

The values of the components in equation 4.17 are given in Table 4.5.

Table 4.5 Descriptions of Variables (Stover-plus)*

Notation	Value	Description	Unit
$\tilde{P}_E$	Variable	Ethanol price	$/gallon
$\tilde{P}_C$	Variable	Corn price	$/bushel
$\tilde{P}_S$	Variable	Corn stover price	$/ton
$\overline{P}_D$	92.85	Dried distiller grains (DDGS) price	$/ton
$\overline{P}_A$	200.00	Ash price	$/ton
$\overline{q}_{S-P} = \frac{\overline{Q}_{S-P}}{\overline{Q}_E}$	0.0009	Stover use per gallon of ethanol, stover-plus	tons/gallon
$\overline{q}_{D-P} = \frac{\overline{Q}_{D-P}}{\overline{Q}_E}$	0.0019	DDGS production per gallon of ethanol, stover	bushels/gallon
$\overline{q}_{A-P} = \frac{\overline{Q}_{A-P}}{\overline{Q}_E}$	0.00021	Ash production per gallon of ethanol, stover-plus	tons/gallon
$\overline{c}_{O-P} = \frac{\overline{C}_{O-P}}{\overline{Q}_E}$	0.4610	Other costs per gallon of ethanol, stover-plus	$/gallon

* See Appendix A for table of efficiency ratios, production and consumption items and the source of data.

From the data given in Table A.1, we know that the integrated other costs and expenses $\overline{c}_{O-P}$ is calculated by

$$\overline{c}_{O-P} = \overline{P}_{El}\,\overline{q}_{El} + \overline{P}_{De}\,\overline{q}_{De} + \overline{P}_{Am}\,\overline{q}_{Am-P} + \overline{P}_{Li}\,\overline{q}_{Li} + \overline{c}_{Ch} + \overline{c}_{Wa} + \overline{c}_{OE} + \overline{c}_{IE-P}$$

$$= 0.05(0.95) + 1.50(0.05) + 500(0.000004) + 25(0.000075) + 0.06 + 0.005$$

$$+ 0.15 + 0.0517 + 0.0480$$

$$= 0.4610$$

Therefore, equation 4.17 can be rewritten as

$$CFG\_P = \tilde{P}_E + 92.85(0.0019) + 200.00(0.00021) - 0.3509\tilde{P}_C - 0.0009\tilde{P}_S - 0.4610$$

Or

$$CFG\_P = \tilde{P}_E - 0.3509\tilde{P}_C - 0.0009\tilde{P}_S - 0.2446 \tag{4.17}$$

Using equation 4.18, we can calculate the monthly CFG from January 2001 to August 2007 and fitted distribution to the 80 calculated CFG_P values. The calculated CFG_P values are given in Table A.2. The fitted normal distribution to CFG_P is given by

$$\text{CFG\_P} \sim \text{RiskNormal}(0.66, 0.54^2) \tag{4.18}$$

That is, the expectation of CFG_P is \$0.66/gallon and the standard deviation is \$0.54/gallon. The plot of CFG_P values is given in Figure 4.7 and the fitted normal distribution to CFG_P is given in Figure 4.8. The risk-free rate is 0.04 and the expected DCFG_P is \$.4095/gallon. Let PVG_P denote the present value per gallon for the stover-plus plant. Using (4.9) and @Risk to do the simulation for PVG_P, the reported volatility value of PVG of the stover-plus plant is 31.38%.

Figure 4.7 Simulated Monthly CFG for Stover-plus Plant, 1/1/1997 – 8/1/2007

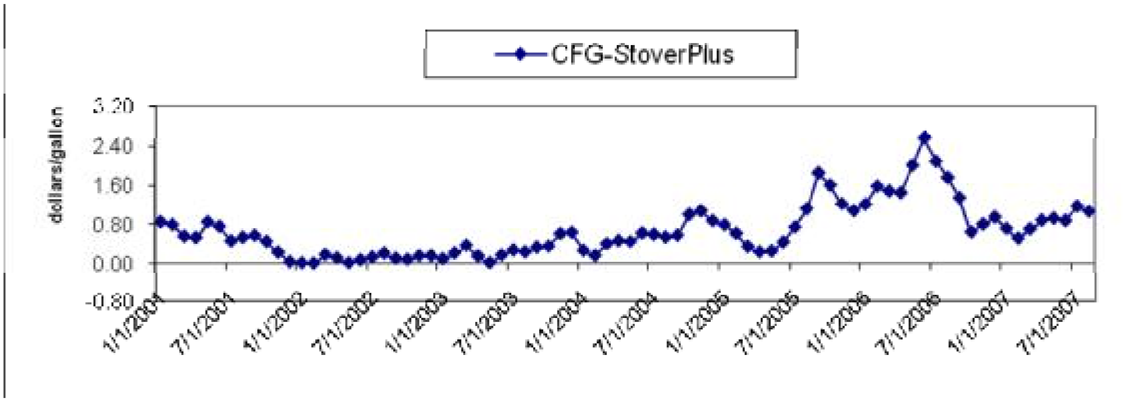
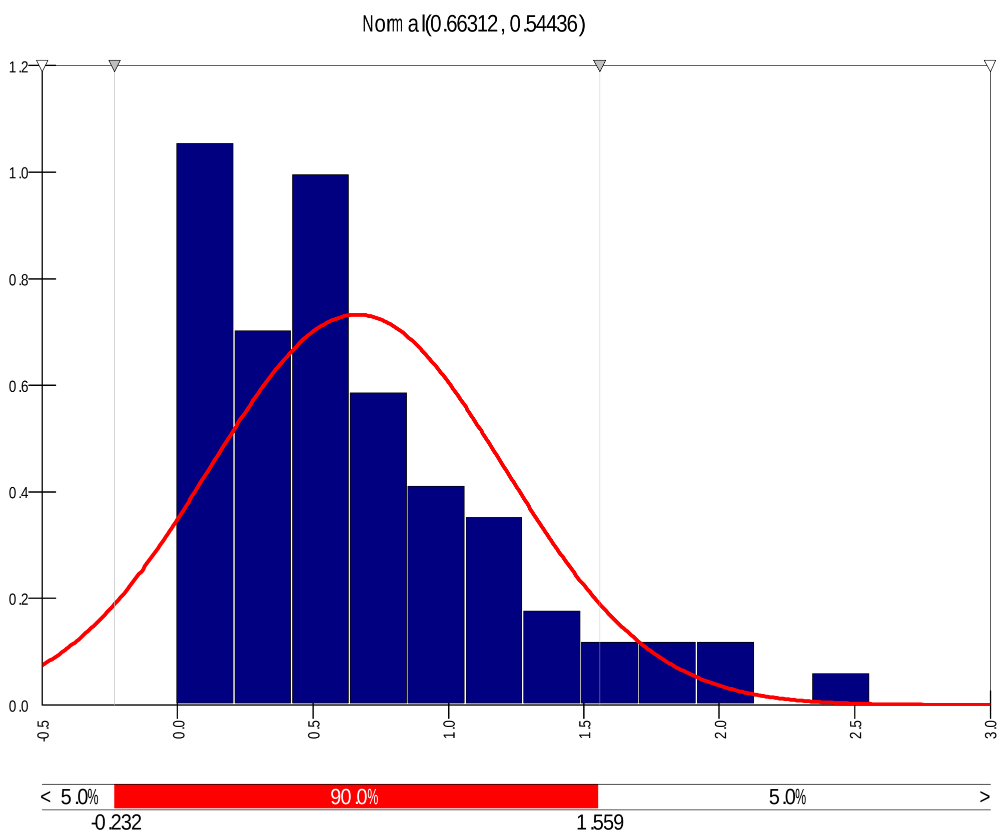


Figure 4.8 Fitted Normal Distribution to CFG_P



We can see that for the whole sample, the volatility values for different technologies are close to each other. However, the volatility of PV in Subperiod II is about 10 percent lower than the other three. If we compare the patterns of CFG exhibited in Figure 4.1, we can find that the CFG for Subperiod I has lower variation while CFG for Subperiod II has higher variation. As a matter of fact, the standard deviation[10] of CFG for Subperiod I is 0.26 and that of CFG for Subperiod II is 0.55. The volatility of CFG for Subperiod I is higher than that for Subperiod II, because volatility reflects the variance in the change of a variable, it is not related to the variance of the variable itself. The summary of fitted distributions is given in Table 4.6.

Table 4.6 Summary of Fitted Distributions and Volatility Values

	Conventional	**Conventional I***	**Conventional II****	**Stover**	**Stover-plus**
Distribution (CFG)	Normal	Normal	Normal	Normal	Normal
Mean (CFG)	$0.59	$0.31	$0.96	$0.68	$0.66
Standard deviation (CFG)	$0.50	$0.26	$0.55	$0.55	$0.54
Volatility, s (PVG)	33.13%	31.42%	21.52%	30.84%	31.38%

* The parameters are estimated based on the historical prices in Subperiod I (May 2002 ~ December 2004)
** The parameters are estimated based on the historical prices in Subperiod II (January 2005 ~ August 2007)

4.2 Risk-free Interest Rate

To estimate the risk-free interest rate r_f, we use the historical interest rate for 3-month U.S. Treasury Bills (USTBs). USTBs are the Treasury securities issued by the U.S. government as debt financing instruments. Usually, USTBs have maturity of one year or less. In the real world, the interest rate on short term USTBs carries the lowest risk, so it is considered to be risk-free. Sometimes, especially for derivative traders, London Interbank Offer Rate (LIBOR) is also used as risk-free rate to define the payoff from a

[10] By abuse of terminology, we simply refer to sample standard deviation as standard deviation, unless otherwise stated.

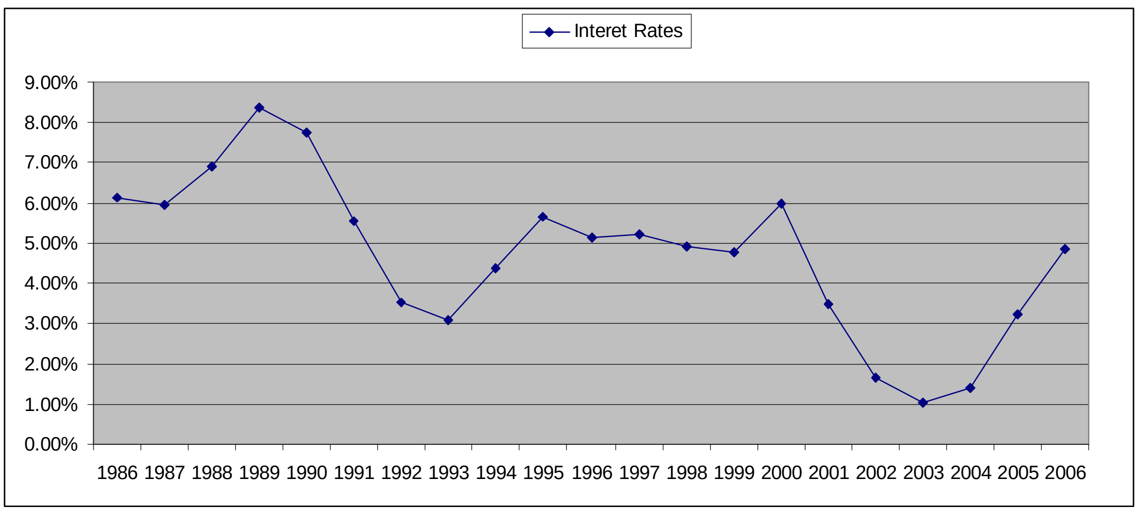
derivative. We use interest rate on USTBs in the estimation because more conservative assumptions need to be made on the return on ethanol asset, and the Treasury rates tend to be lower than LIBOR. The reported annual interest rates of 3-month USTBs from 1982 to 2006 are given in Table 4.7.

Table 4.7 Historical Interest Rates on 3-month U.S. Treasury Bills, 1986-2006

obs	Year	Interest Rate
1	1986	6.15%
2	1987	5.96%
3	1988	6.89%
4	1989	8.39%
5	1990	7.75%
6	1991	5.54%
7	1992	3.51%
8	1993	3.07%
9	1994	4.37%
10	1995	5.66%
11	1996	5.15%
12	1997	5.20%
13	1998	4.91%
14	1999	4.78%
15	2000	6.00%
16	2001	3.47%
17	2002	1.64%
18	2003	1.03%
19	2004	1.40%
20	2005	3.22%
21	2006	4.85%
21-year Average		4.71%
17-year Average		4.21%

The mean of the sample is 4.71%, which is also the 21-year average of the interest rates from 1986 to 2006; the median of the sample is 4.91%. However, the 17-year average of the interest rates from 1990 to 2006 is 4.21%. If we plot the historical interest rates, we can find that the interest rates start deteriorating since 1990 and have a trend of decreasing afterwards. We want to use the average interest rate during this period because it is more likely to reflect the interest level in the recent years. In the real options analysis, we have the base case model built on the historical data on prices from 2001 to 2007, so it is reasonable to use the 17-year average rather than an average for a longer term, going back for more years with much higher interest rates than what we have today. Therefore, the risk-free interest rate used in section 4.1 and in the analysis in Chapter 5 will be 4%, an approximation to the 17-year average.

Figure 4.9 Annual Interest Rates on 3-month U.S. Treasury Bills, 1986-2006



4.3 The Calculation of Other Parameters

The definition and the formulas of calculating the parameters in BOPM are introduced in Chapter 3. Now we can summarize the calculations for these parameters under each combustion technology. Recall that the up-factor and down-factor in BOPM are calculated by

$$u = e^{s\sqrt{\Delta t}}$$

$$d = \frac{1}{u} = e^{-s\sqrt{\Delta t}}$$

The risk-neutral probabilities are given by

$$p_u = p = \frac{R_f - d}{u - d}$$

$$p_d = 1 - p = \frac{u - R_f}{u - d}$$

These four parameters are determined by the value of risk-free rate r_f and volatility σ. For the conventional ethanol plant, we have three estimates for σ. For the other two alternative technologies, we have one estimate for volatility for each of them. The corresponding values of u and d are given in Table 4.8.

Table 4.8 Values of Parameters in BOPM

Parameters	Conventional	Conventional I*	Conventional II**	Stover	Stover-plus
Volatility, s (PVG)	33.13%	31.42%	21.52%	30.84%	31.38%
up-factor, u	1.39	1.37	1.24	1.36	1.37
down-factor, d	0.72	0.73	0.81	0.73	0.73
up-probability, p_u	47.72%	48.47%	53.86%	48.73%	48.49%
down-probability, p_d	52.28%	51.53%	46.14%	51.27%	51.51%

* The parameters are estimated based on the historical prices in Subperiod I (May 2002 ~ December 2004)
** The parameters are estimated based on the historical prices in Subperiod II (January 2005 ~ August 2007)

Chapter 5 Simulations and Analysis for Options of Different Technologies

For an ethanol plant that has been in operation for several years, the investor may consider expanding the existing facilities. However, with the volatile corn price and ethanol price in recent years, the cash flows may also exhibit high volatility. Therefore, the value of the option to expand becomes more important to the investor with such price conditions. By the term of "conventional (ethanol) plant", "conventional technology", or just "conventional", we refer to the dry milling ethanol plant with natural gas combustion technology.

Due to the increasing price of natural gas, the research on using biomass for combustion has developed lower-energy-cost alternatives for producing ethanol. For dry milling ethanol plants, there are two alternative combustion technologies that are available for investors other than conventional natural gas combustion. One is using corn stover as boiler fuel instead of natural gas. In our study, we will refer to this technology as "stover combustion", or simply "stover". The other biomass technology is to use corn stover and syrup as boiler fuel instead of natural gas, or simply "stover-plus".

In this chapter we will evaluate the option to expand a conventional ethanol plant and the corresponding strategies. In later sections we will evaluate the option to choose between conventional versus stover technologies and the option to choose between conventional versus stover-plus technologies. For each of the these options, the corresponding strategies will be evaluated.

5.1 The Option to Expand a Conventional Plant

The base case model is for an ethanol plant with 50mm gpy production capacity using dry milling process and producing 100% dried distiller grains with solubles (DDGS) as byproduct. We assume that by the end of fifth year of plant operation, the investor needs to decide if the plant should be expanded to a 65mm gpy starting from year 6, or if this option should be postponed until later when more favorable market conditions develop.

Let us consider this flexible investment decision as an option to expand, which expires in year 12. That is, if the investment conditions are unfavorable, the investor may postpone the investment to the next year. But this flexibility, i.e., the viability of this option, will not last for more than 6 years, so the option to expand will not be available after year 12 and the expansion can only take place in the interval from year 6 to 12. Furthermore, no matter in which year the expansion project ("the project") will be started, the lifetime of the expansion project will be 7 years, including the first year. For simplicity, we set the first year of viability of the option, year 6, as period 0. Therefore, we let i denote each period of the viability and $i = 0, 1, 2, \ldots, T$, where T is the viability of the option and $T = 6$. So $i = 0$ for year 6, $i = 1$ for year 7, and so on. We also assume that the life time of the project will be equal to T, so when calculating the initial PVG of the conventional expansion, $S = T = 6$ in (4.9). If we assume that CFG follows the normal distribution (4.8), then the expectation of CFG is \$0.59/gallon. So the expectation of total annual cash flow from the project is ($0.59/gallon)*(15mm gpy) = $8.84 million. The disposal cash flow per gallon for the conventional plant DCFG is $0.3375/gallon, so the total expected disposal cash flow from the expansion is ($0.3375/gallon)*(15mm gpy) = $5.06 million. If we assume that there is no variation in the expected cash flows from expansion, then the expected present value E(PV) for the expansion project is given by[11]

$$E(PV) = \sum_{t=0}^{6} \frac{E(CF_t)}{(1+r_f)^t} + \frac{E(DCF)}{(1+r_f)^6}$$
$$= (\frac{\$8.84}{1.04^0} + \frac{\$8.84}{1.04^1} + \frac{\$8.84}{1.04^2} + \frac{\$8.84}{1.04^3} + \frac{\$8.84}{1.04^4} + \frac{\$8.84}{1.04^5} + \frac{\$8.84}{1.04^6}) + \frac{\$5.06}{1.04^6}$$
$$= \$57.06 \quad (million)$$

We may also assume that there is no variation of the period-zero E(PV) regardless the year in which the project will be launched. If the investor decides that the expansion will occur in period 0 (year 6), the expected PV of the expansion project in period 0 will be the discounted CFs from year 7 to year 12 plus the discounted DCF, and E(PV) is $57.06; if the investor decides to expand in period 1, the expected PV of the project in period 1 will be the discounted CFs from year 8 to year 13 plus the discounted DCF, and E(PV) equals $57.06, and so on. The calculations of the "moving" PVs and CFs are given in Figure 5.1.

[11] Equation 4.9 is for calculating PVG (present value per gallon), it can also used to calculate the total PV (present value). We simply replace the PVG with PV, CFG with CF, and DCFG with DCF in equation 4.9.

Figure 5.1 Present Values without Volatility, Conventional Expansion

Year =>	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period i (viability) =>						0	1	2	3	4	5	6						
E(PV) of Expansion, Starting in ith period =>						$ 57.06	$ 57.06	$57.06	$57.06	$57.06	$57.06	$57.06						
Starts in Period 0 =>					E(OCF)	$ 8.84	$ 8.84	$ 8.84	$ 8.84	$ 8.84	$ 8.84	$ 8.84						
Starts in Period 1 =>					E(OCF)		$ 8.84	$ 8.84	$ 8.84	$ 8.84	$ 8.84	$ 8.84	$ 8.84					
Starts in Period 2 =>					E(OCF)			$ 8.84	$ 8.84	$ 8.84	$ 8.84	$ 8.84	$ 8.84	$ 8.84				
Starts in Period 3 =>					E(OCF)				$ 8.84	$ 8.84	$ 8.84	$ 8.84	$ 8.84	$ 8.84	$ 8.84			
Starts in Period 4 =>					E(OCF)					$ 8.84	$ 8.84	$ 8.84	$ 8.84	$ 8.84	$ 8.84	$ 8.84		
Starts in Period 5 =>					E(OCF)						$ 8.84	$ 8.84	$ 8.84	$ 8.84	$ 8.84	$ 8.84	$ 8.84	
Starts in Period 6 =>					E(OCF)							$ 8.84	$ 8.84	$ 8.84	$ 8.84	$ 8.84	$ 8.84	$ 8.84

Figure 5.2 Binomial Tree of Asset Values – Present Values with Volatility, Conventional Expansion

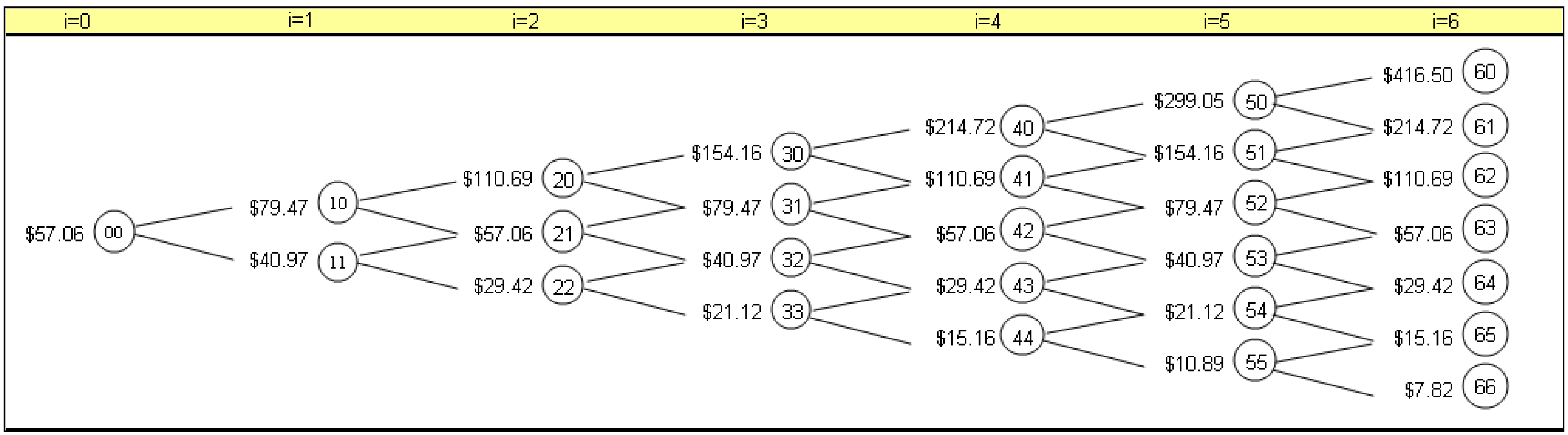


Figure 5.1 illustrates the projection for CFs and PVs without volatility. As a matter of fact, when we try to establish the BOPM, we are looking into the future at period 0, and this is the initial period. At this point, we can assume that if the project is exercised in period 0, then the PV of the project is just the PV without volatility, that is, \$57.06 million. This is also called the initial value of the asset. However, we may need to decide if we will have to launch the project in period 1 or even later period while we are still at the point of period 0. With the time going further into the future, more uncertainty will be added. This is why we need to consider volatility for the future CFs and PVs. We know from Chapter 4 that when we assume that the CFG in each year follows the normal distribution (4.8), the volatility of PVG is 33.13%. Since the production will not be varying from period to period, the expected CF will follow the same distribution as CFG and PV will have the same volatility as PVG. Then the binomial tree of PV is given by Figure 5.2. Let V_{ij} denote the expected PV at node ij (i = 0, 1, 2, …, 6, j = 0, 1, 2, …, 6), then for $i, j \neq 0$, V_{ij} is calculated by

$$V_{ij} = u^{i-j} d^{j} V_{00} \tag{5.1}$$

In equation 5.1, V_{00} denotes the initial value of the asset and V_{00} = \$57.06 by equation (4.9). Using equations 3.1 and 3.2, we can calculate the value of up-factor u and down-factor d:

$$u = e^{s\sqrt{\Delta t}} = e^{33.13\%} = 1.39$$

$$d = e^{-s\sqrt{\Delta t}} = \frac{1}{u} = 1/1.39 = 0.72$$

Recall that as we discussed in Chapter 3, $\Delta t = 1$ in our model. Therefore, equation 5.1 can be rewritten as

$$V_{ij} = 1.39^{i-j} 0.72^{j} 57.06 \qquad \text{for } i, j \neq 0 \qquad (5.2)$$

For examples, at nodes 10, 11, 20, 21, and 22, the asset values are given by

$$V_{10} = uV_{00} = 1.39(\$57.06) = \$79.47 \ \ (million)$$

$$V_{11} = dV_{00} = 0.72(\$57.06) = \$40.97 \ \ (million)$$

$$V_{20} = u^2V_{00} = 1.39^2(\$57.06) = \$110.69 \ \ (million)$$

$$V_{21} = udV_{00} = 1.39(0.72)(\$57.06) = \$57.06 \ \ (million)$$

$$V_{22} = d^2V_{00} = 0.72^2(\$57.06) = \$29.42 \ \ (million)$$

Since the binomial tree of asset values has been established, we now can evaluate the option values (of the expansion project) at each node of the tree. First, we need to determine the up-probability p_u and down-probability p_d. We use 4% as risk-free interest rate. By equations 3.16 and 3.17, we have

$$p_u = \frac{R_f^{\Delta t} - d}{u - d} = \frac{1 + r_f - d}{u - d} = \frac{1 + 4\% - 0.72}{1.39 - 0.72} = 47.72\%$$

$$p_d = 1 - p_u = 1 - 47.72\% = 52.28\%$$

The up-probability is 47.72%, which means that the asset value at each node has a 47.72% probability to go up at next period; the down-probability is 52.28%, which means that the asset value at each node has 52.28% probability to go down at next period. For examples, there is 47.72% of chance for V_{00} ($57.06 million) to increase to V_{10} ($79.47 million) at period 1 and there is 52.28% of chance for V_{00} to decline to V_{11} ($40.97 million) at period 1. If we look into the periods beyond period 1, then the probability of V_{10} ($79.47 million) to increase to V_{20} ($110.69 million) at period 2 is 47.72% and the probability of V_{10} to decline to V_{21} ($57.06 million) at period 2 is 52.28%. The probability of V_{11} ($40.97 million) to increase to V_{21} ($57.06 million) at period 2 is 47.72% and the probability of V_{11} to decline to V_{22} ($29.42 million) at period 2 is 52.28%, and so on.

Using the binomial tree of asset values in Figure 5.2, we can now derive the binomial tree of option values. From equations 3.20 and 3.21, we know that we will need to compare the value of waiting with the NPV of the asset to determine the option values. So, first we will establish the binomial tree of NPVs of the project. The NPV at node ***ij*** (***i*** = 0, 1, 2, …, 6 and ***j*** = 0, 1, 2, …, 6) is calculated by

$$NPV_{ij} = V_{ij} - X \tag{5.3}$$

In equation 5.3, X is the exercise price of the project, which in this scenario equals the construction cost for the expansion. From Table A.1 we know that for a conventional plant, the construction cost is \$2.25/gallon. Therefore, for a 15 mm gpy expansion, the total construction cost is \$2.25(15) = \$33.75 million. So X = \$33.75 million in equation 5.3. The binomial tree of NPVs is given by Figure 5.3.

Recall that we derive the option values starting from the expiration date of the option, period 6, because at expiration, the problem becomes a "now-or-never" problem. That is, only when the net present value of the asset is positive, the project will be launched at expiration. Otherwise, the project will be rejected forever. The binomial tree of option values is given in Figure 5.4. By equation 3.20, we know that the option value C_{ij} (for i = 6 and j = 0,1, 2, …, 6) at expiration is given by

$$C_{ij} = Max\{0, V_{ij} - X\} \tag{5.4}$$

For examples, the option values at nodes 60, 61, 62, 63, and 64 are

$$C_{60} = Max\{0, V_{60} - X\} = Max\{0, \$416.50 - \$33.75\} = \$382.75 \ \ (million)$$

$$C_{61} = Max\{0, V_{61} - X\} = Max\{0, \$214.72 - \$33.75\} = \$180.97 \ \ (million)$$

$$C_{62} = Max\{0, V_{62} - X\} = Max\{0, \$110.69 - \$33.75\} = \$76.94 \ \ (million)$$

$$C_{63} = Max\{0, V_{63} - X\} = Max\{0, \$57.06 - \$33.75\} = \$23.31 \ \ (million)$$

$$C_{64} = Max\{0, V_{64} - X\} = Max\{0, \$29.42 - \$33.75\} = 0 \ \ (million)$$

By equation 3.21, we know that before the expiration date, the option values C_{ij} 's (for i = 0, 1, …, 5 and j = 0, 1, …, 6) are determined by

$$C_{ij} = Max\{R_f^{-1}(p_u C_{i+1,u} + p_d C_{i+1,d}), V_{ij} - X\} \tag{5.5}$$

where R_f is calculated by

$$R_f = \frac{1}{1+r_f} = \frac{1}{1+0.04} = 0.96$$

Let us look at some examples on the calculations for the option values in period 5:

$$\begin{aligned} C_{50} &= Max\{R_f^{-1}(p_u C_{60} + p_d C_{61}), V_{50} - X\} \\ &= Max\{0.96[47.72\%(\$382.75) + 52.28\%(\$180.97)], \$299.05 - \$33.75\} \\ &= Max\{\$266.60, \$265.30\} \\ &= \$266.60 \end{aligned}$$

$$\begin{aligned} C_{51} &= Max\{R_f^{-1}(p_u C_{61} + p_d C_{62}), V_{51} - X\} \\ &= Max\{0.96[47.72\%(\$180.97) + 52.28\%(\$76.94)], \$154.16 - \$33.75\} \\ &= Max\{\$121.71, \$120.41\} \\ &= \$121.71 \end{aligned}$$

$$\begin{aligned} C_{52} &= Max\{R_f^{-1}(p_u C_{62} + p_d C_{63}), V_{52} - X\} \\ &= Max\{0.96[47.72\%(\$76.94) + 52.28\%(\$23.31)], \$79.47 - \$33.75\} \\ &= Max\{\$47.02, \$45.72\} \\ &= \$47.02 \end{aligned}$$

$$
\begin{aligned}
C_{53} &= Max\left\{R_f^{-1}(p_u C_{63} + p_d C_{64}), V_{53} - X\right\} \\
&= Max\{0.96[47.72\%(\$23.31) + 52.28\%(\$0.00)], \$40.97 - \$33.75\} \\
&= Max\{\$10.70, \$7.22\} \\
&= \$10.70
\end{aligned}
$$

$$
\begin{aligned}
C_{54} &= Max\left\{R_f^{-1}(p_u C_{64} + p_d C_{65}), V_{54} - X\right\} \\
&= Max\{0.96[47.72\%(\$0.00) + 52.28\%(\$0.00)], \$21.12 - \$33.75\} \\
&= Max\{\$0.00, -\$12.63\} \\
&= \$0.00
\end{aligned}
$$

$$
\begin{aligned}
C_{55} &= Max\left\{R_f^{-1}(p_u C_{65} + p_d C_{66}), V_{55} - X\right\} \\
&= Max\{0.96[47.72\%(\$0.00) + 52.28\%(\$0.00)], \$10.89 - \$33.75\} \\
&= Max\{\$0.00, -\$22.86\} \\
&= \$0.00
\end{aligned}
$$

Similarly, to determine the option values in period 4, we need to go backward from period 5 to period 4. The option values in period 4 are given by

$$
\begin{aligned}
C_{40} &= Max\left\{R_f^{-1}(p_u C_{50} + p_d C_{51}), V_{40} - X\right\} \\
&= Max\{0.96[47.72\%(\$266.60) + 52.28\%(\$121.71)], \$214.72 - \$33.75\} \\
&= Max\{\$183.51, \$180.97\} \\
&= \$183.51
\end{aligned}
$$

$$
\begin{aligned}
C_{41} &= Max\left\{R_f^{-1}(p_u C_{51} + p_d C_{52}), V_{41} - X\right\} \\
&= Max\{0.96[47.72\%(\$121.71) + 52.28\%(\$47.02)], \$110.69 - \$33.75\} \\
&= Max\{\$79.49, \$76.94\} \\
&= \$79.49
\end{aligned}
$$

$$
\begin{aligned}
C_{42} &= Max\left\{R_f^{-1}(p_u C_{52} + p_d C_{53}), V_{42} - X\right\} \\
&= Max\{0.96[47.72\%(\$47.02) + 52.28\%(\$10.70)], \$57.06 - \$33.75\} \\
&= Max\{\$26.95, \$23.31\} \\
&= \$26.95
\end{aligned}
$$

Figure 5.3 NPVs – Conventional Expansion

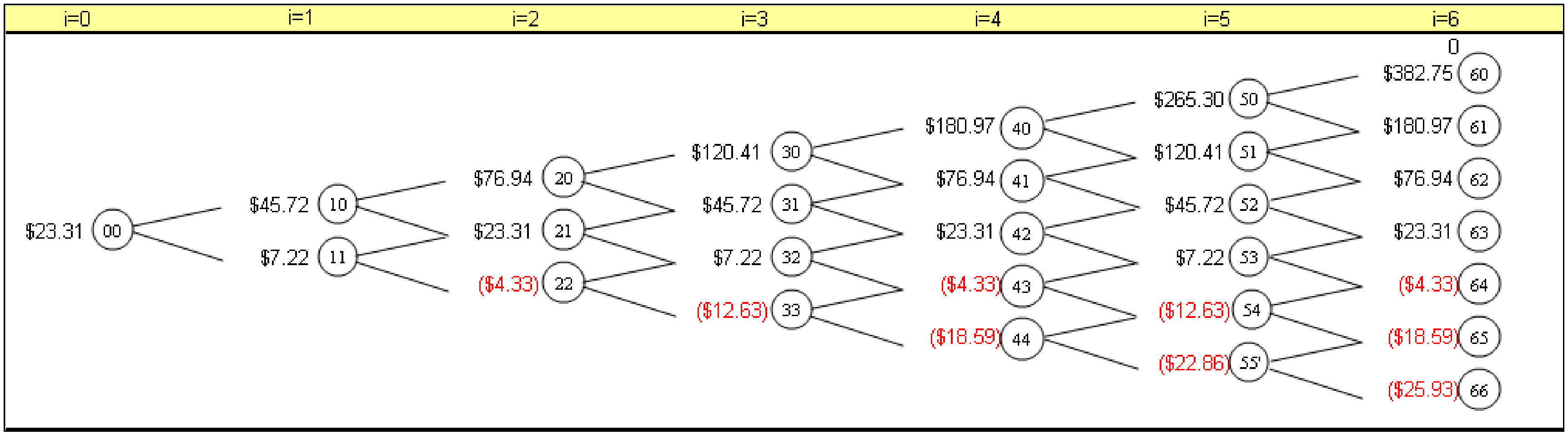
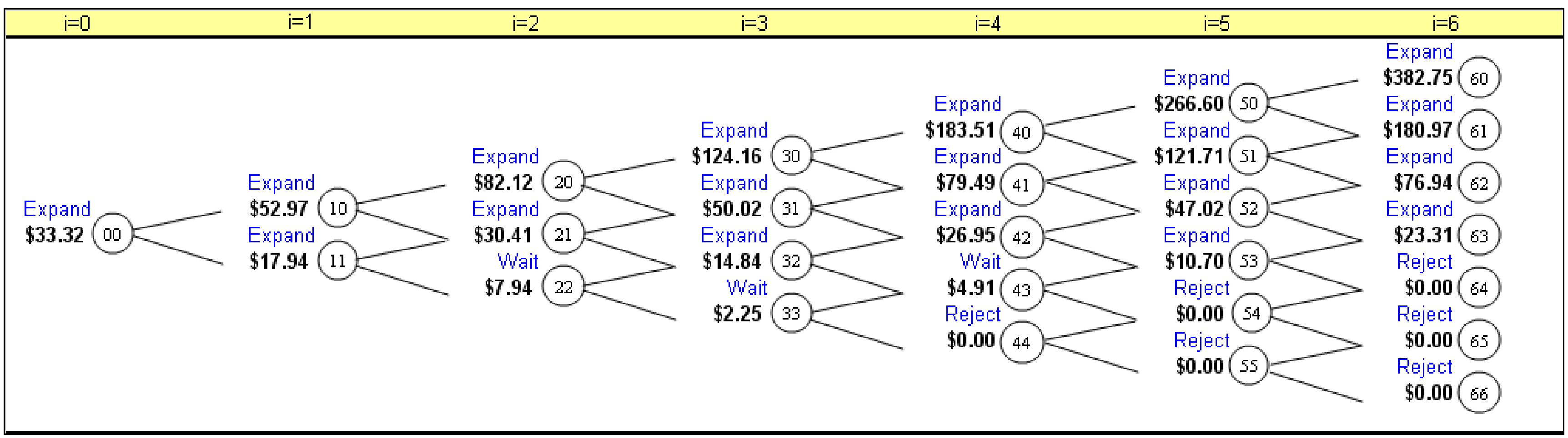


Figure 5.4 Option Values and Strategies – Conventional Expansion



$$
\begin{aligned}
C_{43} &= Max\left\{R_f^{-1}(p_u C_{53} + p_d C_{54}), V_{43} - X\right\} \\
&= Max\{0.96[47.72\%(\$10.70) + 52.28\%(\$0.00)], \$29.42 - \$33.75\} \\
&= Max\{\$4.91, -\$4.33\} \\
&= \$4.91
\end{aligned}
$$

$$
\begin{aligned}
C_{44} &= Max\left\{R_f^{-1}(p_u C_{54} + p_d C_{55}), V_{44} - X\right\} \\
&= Max\{0.96[47.72\%(\$0.00) + 52.28\%(\$0.00)], \$15.16 - \$33.75\} \\
&= Max\{\$0.00, -\$18.59\} \\
&= \$0.00
\end{aligned}
$$

We can see from the above calculations that the option values are determined by the present value of waiting until next period and the NPV of investing at the current period. For instance, C_{40} = \$183.51 because $R_f^{-1}(p_u C_{50} + p_d C_{51}) > V_{40} - X$ and $R_f^{-1}(p_u C_{50} + p_d C_{51}) > 0$. However, if we recall the criteria of determine the investment strategies in section 3.2, the strategy at node 40 is to expand, although the NPV of investing \$183.26 million does not exceed the value of waiting \$183.51 million, the investor will still have a positive NPV from investing in period 4 with the given conditions at node 40. That is, $NPV_{40} = V_{40} - X > 0$. So according to the criteria in section 3.2, the strategy is illustrated as “Expand” at node 40. The strategies at node 41 and 42 are derived in a similar way.

If we look at node 43, we can see that the strategy illustrated is “Wait”. This is because $R_f^{-1}(p_u C_{53} + p_d C_{54}) > 0 > V_{43} - X$. We know that $R_f^{-1}(p_u C_{53} + p_d C_{54}) = \$4.91$ million and $V_{43} - X$ = -\$4.33 million. The NPV of the project is negative while there is still value of waiting since 4.91 >0. So if the condition underlying node 43 happens, the investor may wait until the next period. The underlying condition at node 43 is actually the NPV (with volatility) of the expansion at this node.

The strategy at node 44 is “Reject”. This is because the value of waiting is zero and the NPV is negative. That is, $R_f^{-1}(p_u C_{54} + p_d C_{55}) = \$0.00$ million and $V_{44} - X$ = -$18.59 million. So if the condition underlying node 44 happens, the investor may reject the project forever.

Recall that the volatility 33.13% is a recapture of the historical volatility of PV from January 2001 to August 2007. We also know from Chapter 4 that the volatility of PVG for Subperiod I and Subperiod II are different from that of the whole period. The distributions of CFs of these two subperiods are also different from that of the whole sample. What if the history in either of these two subperiods will replay in the future? To answer this question, we can just apply the volatility values of PVG for these two subperiods to the BOPM with all else equal. The volatility of PV for Subperiod I (May 2002 to December 2004) is 31.42%, and the volatility of PV for Subperiod II (January 2005 to August 2007) is 21.52%. Correspondingly, when the volatility equals 31.42%, we name this case as “Conventional Expansion I” (“Expansion I”). By distribution 4.10, the expectation of CFG is $0.3072/gallon, so the expected CF from the 15 million gpy expansion is $4.61 million. The expected initial PV of the expansion project is $31.66 million by (4.9). The up-factor *u* is 1.37 by equation 3.1 and the down-factor *d* is 0.73 by equation 3.2. The up-probability p_u is 48.47% by equation 3.16 and the down-probability p_d is 51.53% by equation 3.17. The flat projection of PVs through the six years of viability is given in Figure 5.5 and the binomial tree of PVs for Expansion I is given in Figure 5.6. The NPVs of Expansion I are given in Figure **5.7** and the option values and strategies of Expansion I are given in Figure 5.8.

We can see from Figure 5.7 that the initial NPV is negative, which equals -$2.09 million. By traditional NPV approach, the project will be rejected at node 00. However, if we look at the binomial tree in Figure 5.8, we can see that the option value at node 00 is $11.31 million, so we have a positive option value and it suggests that the investor may wait until the next period according to real options approach (ROA). In period 1, if the NPV is to increase (to $9.60 million at node 10), then the strategy is to expand and option value is $19.27 million. If the NPV in period 1 is to decrease (to -$10.63 million), then the strategy is to wait but not reject the project, since the option value is $4.70 million. So we can see how the ROA will affect the investment decisions differently.

Figure 5.5 Present Values without Volatility, Conventional Expansion I

Year =>	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period i (viability) =>						0	1	2	3	4	5	6						
E(PV) of Expansion, Starting in ith period =>						$ 31.66	$ 31.66	$31.66	$31.66	$31.66	$31.66	$31.66						
Starts in Period 0 =>					E(OCF)	$ 4.61	$ 4.61	$ 4.61	$ 4.61	$ 4.61	$ 4.61	$ 4.61						
Starts in Period 1 =>					E(OCF)		$ 4.61	$ 4.61	$ 4.61	$ 4.61	$ 4.61	$ 4.61	$ 4.61					
Starts in Period 2 =>					E(OCF)			$ 4.61	$ 4.61	$ 4.61	$ 4.61	$ 4.61	$ 4.61	$ 4.61				
Starts in Period 3 =>					E(OCF)				$ 4.61	$ 4.61	$ 4.61	$ 4.61	$ 4.61	$ 4.61	$ 4.61			
Starts in Period 4 =>					E(OCF)					$ 4.61	$ 4.61	$ 4.61	$ 4.61	$ 4.61	$ 4.61	$ 4.61		
Starts in Period 5 =>					E(OCF)						$ 4.61	$ 4.61	$ 4.61	$ 4.61	$ 4.61	$ 4.61	$ 4.61	
Starts in Period 6 =>					E(OCF)							$ 4.61	$ 4.61	$ 4.61	$ 4.61	$ 4.61	$ 4.61	$ 4.61

Figure 5.6 Binomial Tree of Asset Values – Present Values with Volatility, Conventional Expansion I

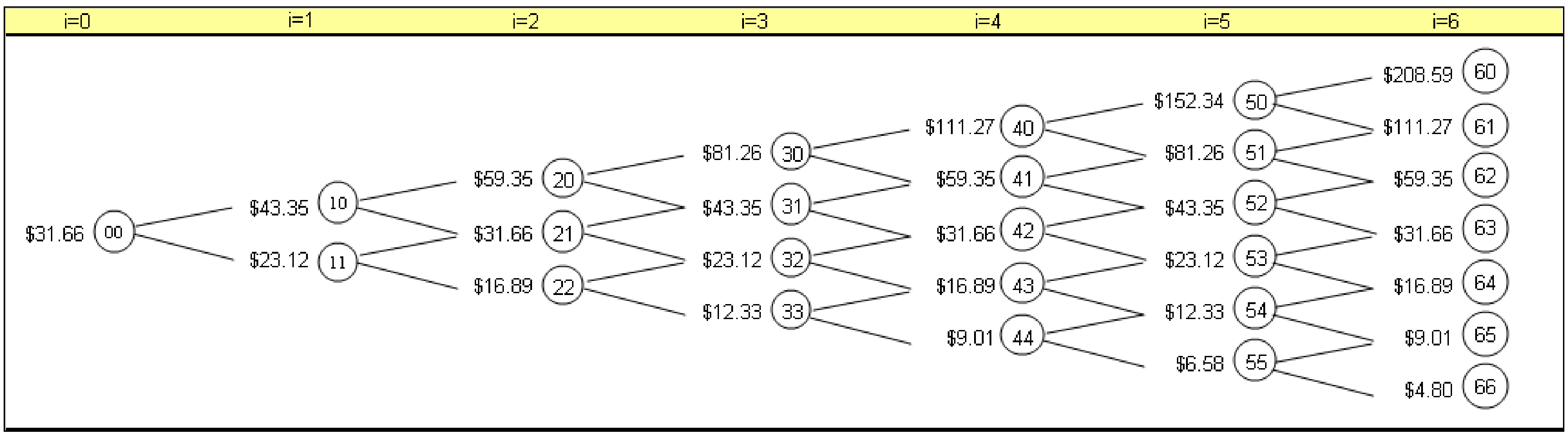


Figure 5.7 NPVs – Conventional Expansion I

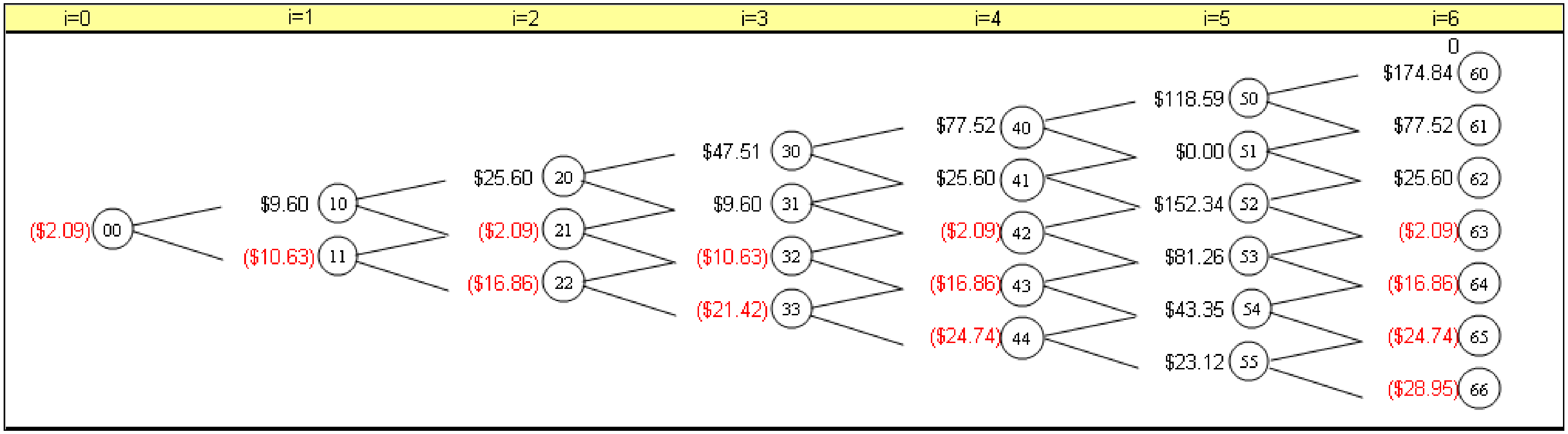
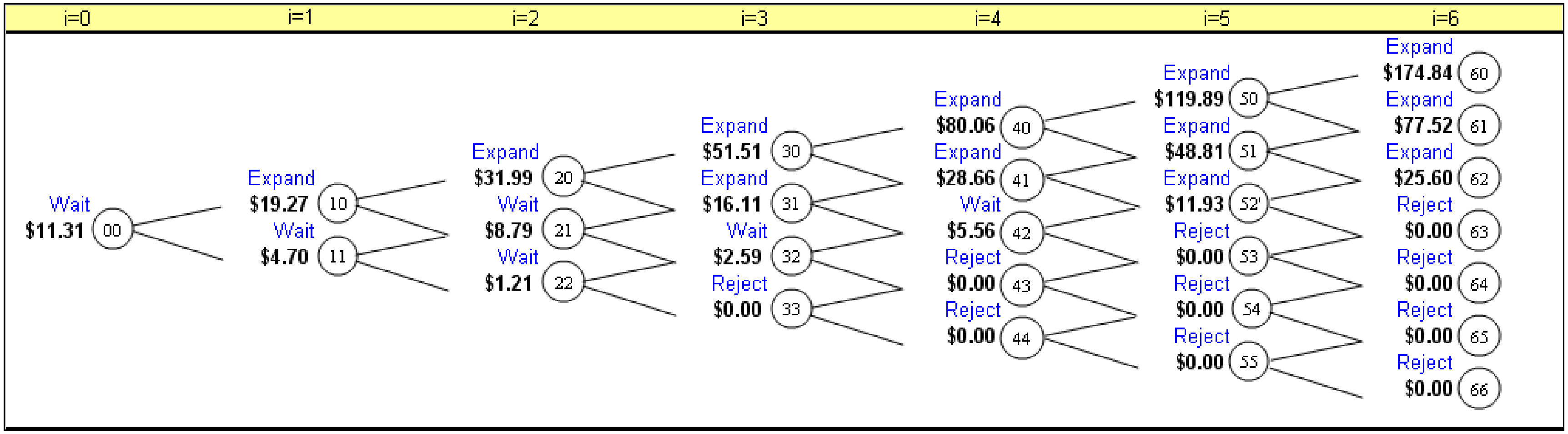


Figure 5.8 Option Values and Strategies – Conventional Expansion I



If the history from January 2005 to August 2007 is to replay in the future, then the expected volatility equals 21.52%. We name this case of expansion as “Conventional Expansion II” or just “Expansion II”. By distribution 4.11, the expectation of CFG is $0.9593/gallon, so the expected CF from the 15 million gallons expansion is $14.39 million. Using equation (4.9), the expected initial PV is $93.82 million. The up-factor ***u*** is 1.24 and the down-factor ***d*** is 0.81. The up-probability p_u is 53.86% by equation 3.16 and the down-probability p_d is 46.14% by equation 3.17. The flat projection of the expected PVs in the future is given in Figure 5.9 and the projection of PVs with expected volatility during the six years viability is given in Figure 5.10. The NPVs corresponding to the binomial tree of PVs is given in Figure 5.11 and the option values and strategies are given in Figure 5.12.

Because we assume that the exercise price will be the same regardless of the change of volatility value and the exercise price will also be constant throughout the six years of viability, in Expansion II, the higher initial value $93.82 leads to higher initial NPV $60.07. Consequently, the NPVs throughout the binomial tree are all positive expect for node 66. This is a most optimal case for the investor: lowest volatility and highest expectation of asset values (PVs). The strategies are suggested to be “Expand” at all the nodes except for node 66. The real option expires in period 6 and because the NPV at node 66 is negative, the project will be rejected forever if the condition at node 66 happens.

Figure 5.9 Present Values without Volatility, Conventional Expansion II

Year =>	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period i (viability) =>						0	1	2	3	4	5	6						
E(PV) of Expansion, Starting in ith period =>						$ 93.82	$ 93.82	$93.82	$93.82	$93.82	$93.82	$93.82						
Starts in Period 0 =>					E(OCF)	$ 14.39	$ 14.39	$ 14.39	$ 14.39	$ 14.39	$ 14.39	$ 14.39						
Starts in Period 1 =>					E(OCF)		$ 14.39	$ 14.39	$ 14.39	$ 14.39	$ 14.39	$ 14.39	$ 14.39					
Starts in Period 2 =>					E(OCF)			$ 14.39	$ 14.39	$ 14.39	$ 14.39	$ 14.39	$ 14.39	$ 14.39				
Starts in Period 3 =>					E(OCF)				$ 14.39	$ 14.39	$ 14.39	$ 14.39	$ 14.39	$ 14.39	$ 14.39			
Starts in Period 4 =>					E(OCF)					$ 14.39	$ 14.39	$ 14.39	$ 14.39	$ 14.39	$ 14.39	$ 14.39		
Starts in Period 5 =>					E(OCF)						$ 14.39	$ 14.39	$ 14.39	$ 14.39	$ 14.39	$ 14.39	$ 14.39	
Starts in Period 6 =>					E(OCF)							$ 14.39	$ 14.39	$ 14.39	$ 14.39	$ 14.39	$ 14.39	$ 14.39

Figure 5.10 Binomial Tree of Asset Values – Present Values with Volatility, Conventional Expansion II

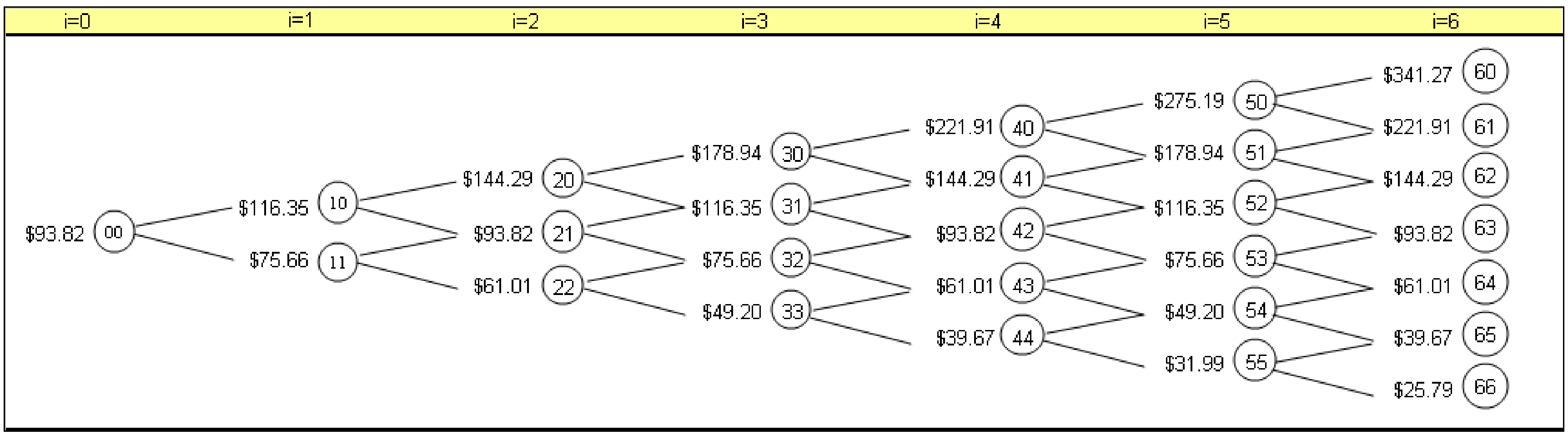


Figure 5.11 NPVs – Conventional Expansion II

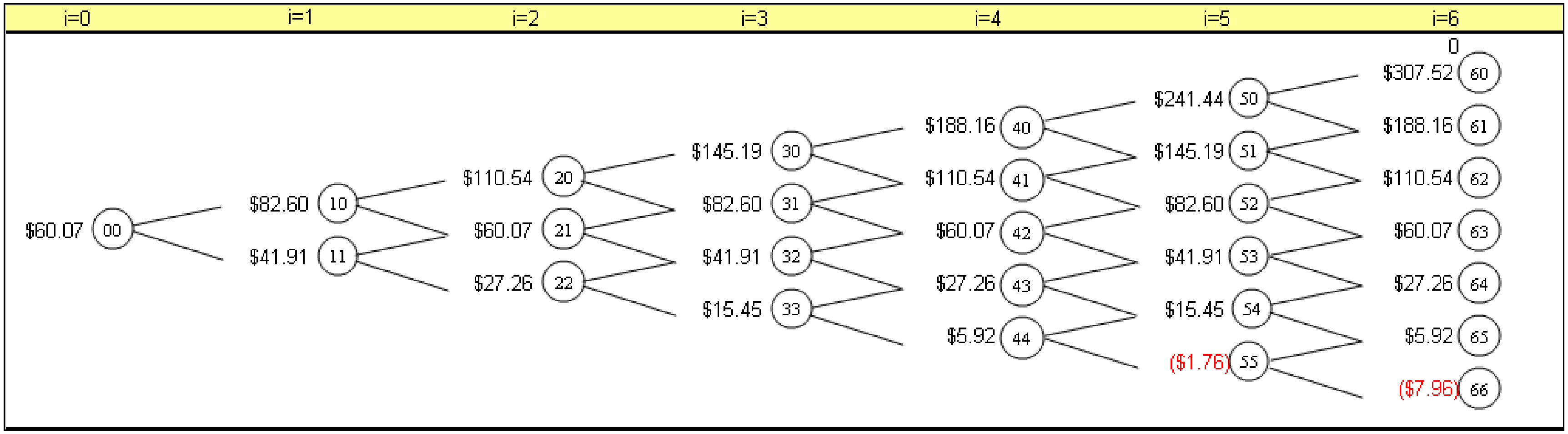
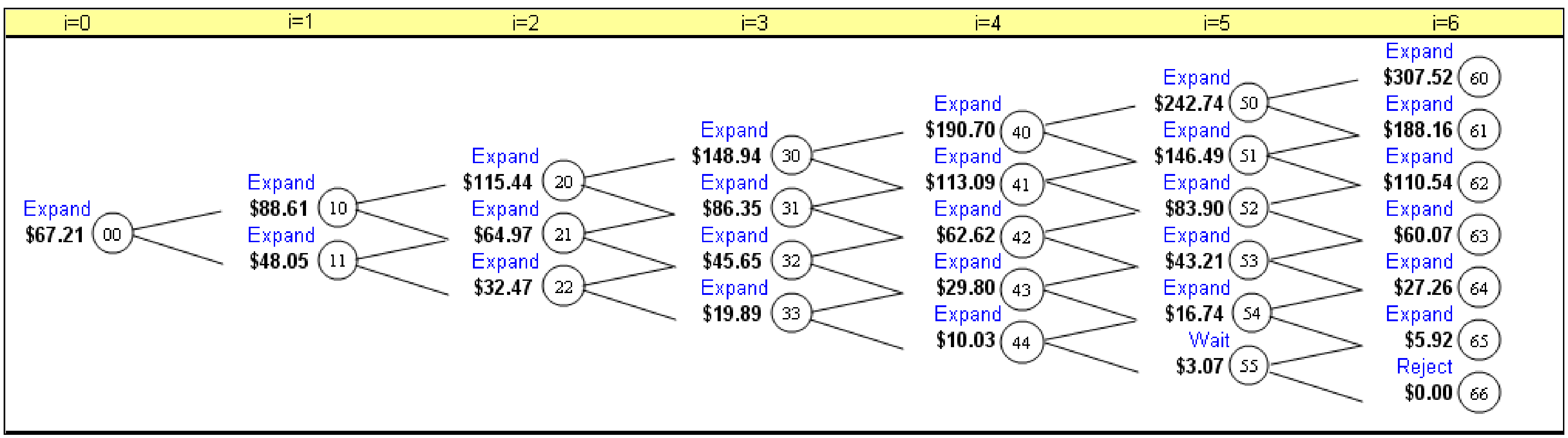


Figure 5.12 Option Values and Strategies – Conventional Expansion II



5.2 The Option to Choose a Conventional Plant versus a Stover Plant

As introduced in Chapter 4, a stover plant is supposed to be more energy-efficient than a conventional plant. To evaluate the real option values of choosing conventional versus stover for a new startup project, we apply the estimated volatility 33.13% to the conventional plant and the calibrated volatility 31.42% to the stover plant, and then we compare the NPVs of the conventional plant and the stover plant. Let us name this option as Technology-option 1. The comparison for parameters in BOPM for both plants is given in Table 5.1.

Table 5.1 Comparison for Parameters, Conventional versus Stover

	Conventional	Stover	Unit
Nameplate	50	50	mm gpy
S, Plant Life	15	15	years
Initial Investment	\$112.50	\$147.00	million
E(DCF)	\$16.88	\$22.05	million
E(CFG)	\$0.59	\$0.68	\$/gallon
E(CF)	\$29.47	\$33.92	million
rf, risk-free rate	0.04	0.04	
R=1+rf	1.04	1.04	
R^{-1}=1/(1+rf)	0.96	0.96	
T, viability	6	6	years
D**t, time interval**	1	1	years
σ, volatility	33.13%	32.11%	
u, up factor	1.38	1.38	
d, down factor	0.72	0.73	
pu, prob-up	47.72%	48.16%	
pd, prob-down	52.28%	51.84%	

To establish the BOPM of this option, first we need to determine the initial values of the underlying assets. We know that the present value of an ethanol asset is calculated by (4.9), so the expected initial present value of the conventional plant is

$$\left(\frac{\$29.47}{1.04}+\frac{\$29.47}{1.04^2}+\frac{\$29.47}{1.04^3}+...+\frac{\$29.47}{1.04^{14}}+\frac{\$29.47}{1.04^{15}}\right)+\frac{\$16.88}{1.04^{15}}=\$337.01 \text{ million}$$

and the expected initial present value of the stover plant is

$$\left(\frac{\$33.92}{1.04}+\frac{\$33.92}{1.04^2}+\frac{\$33.92}{1.04^3}+...+\frac{\$33.92}{1.04^{14}}+\frac{\$33.92}{1.04^{15}}\right)+\frac{\$22.05}{1.04^{15}}=\$389.41 \text{ million}$$

Using equation 5.1, we can establish the binomial trees of asset values under volatility for the conventional and the stover, respectively. The comparison of these two binomial trees is given in Figure 5.13. We can see that because the initial value of the conventional plant is lower than that of the stover plant, and the volatility of present values of these two assets is about the same, the asset value at each node in the conventional binomial tree is larger than the asset value at the corresponding node in the stover binomial tree. By equation 5.3, the binomial trees of NPVs for both plants are given in Figure 5.14. Because the exercise price for a stover plant is higher than that of a conventional plant, the NPVs of the stover plant are deteriorating faster than the NPVs of the conventional plant.

To estimate the option values of Technology-option 1, we first use equations 3.20 and 3.21 to establish the binomial tree for the option to start a new conventional plant and the binomial tree for the option to start a new stover plant. From Table 5.1 we know that both options have the same length of lifetime, the same viability, and the same productivity. Then we will compare the NPVs and option values from both technologies to determine the option values and strategies of tech-opion1. The two binomial trees are given in Figure 5.15.

Figure 5.13 Asset Values for Conventional versus Stover

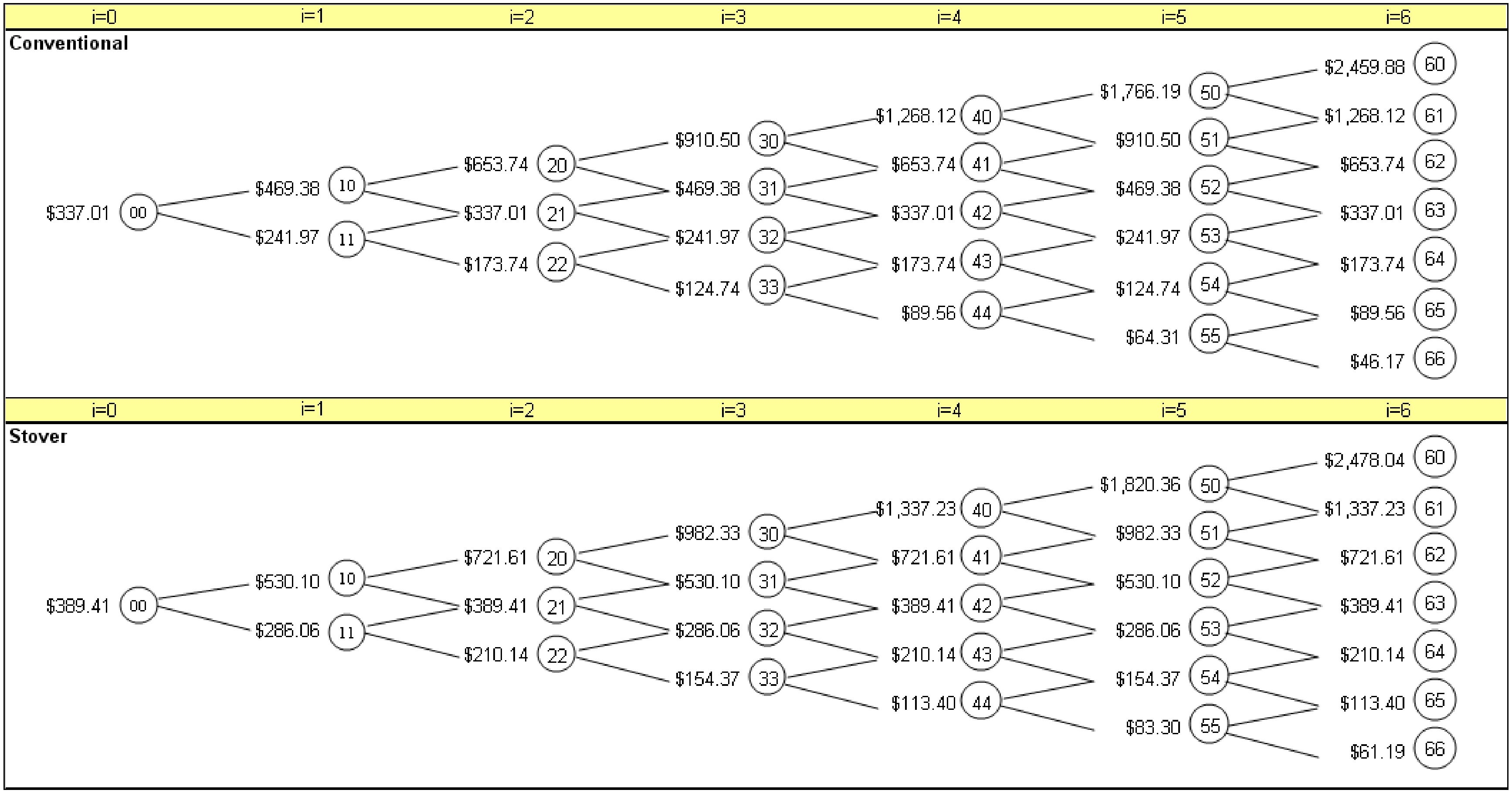


Figure 5.14 Net Present Values for Conventional versus Stover

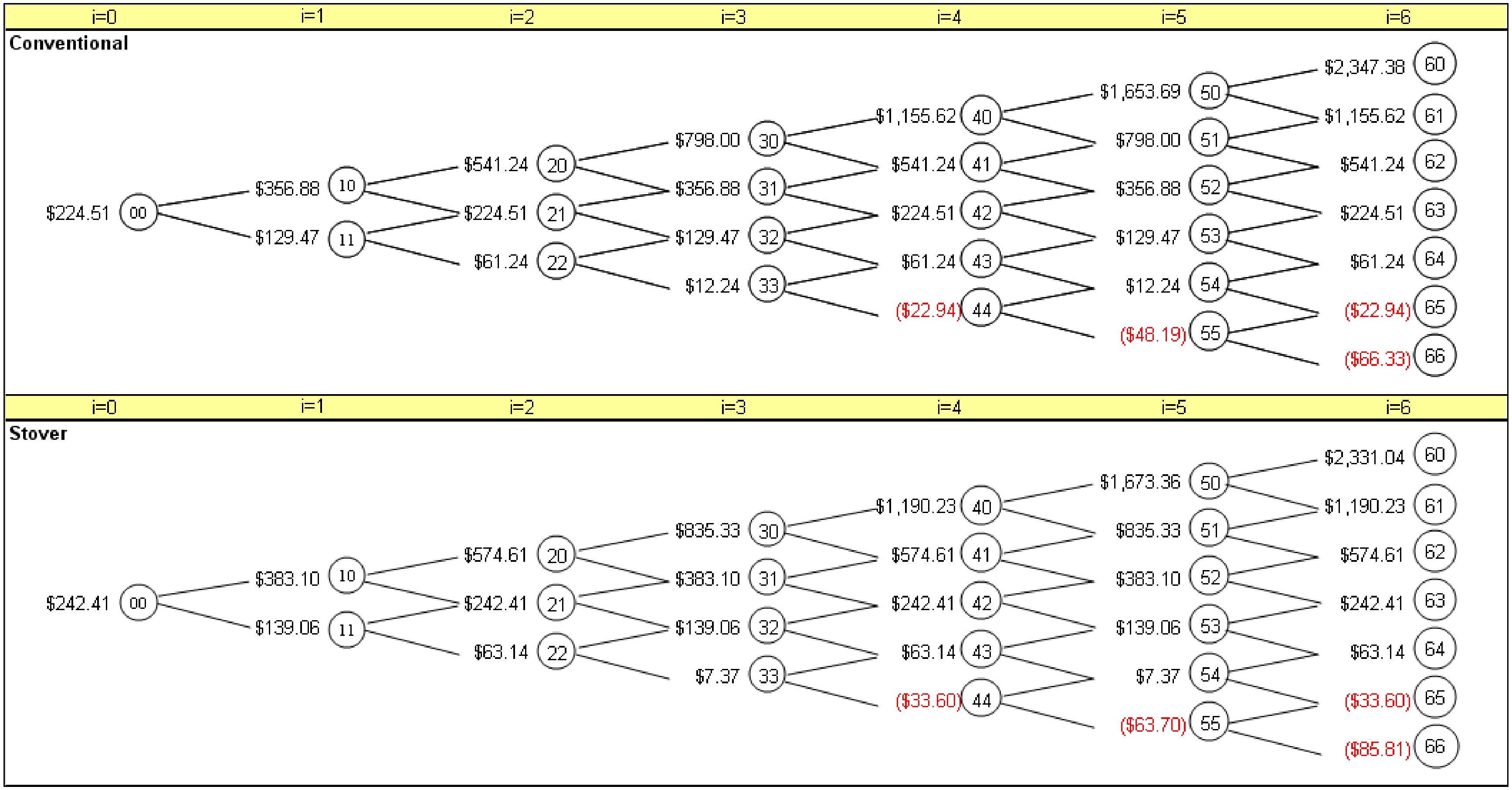
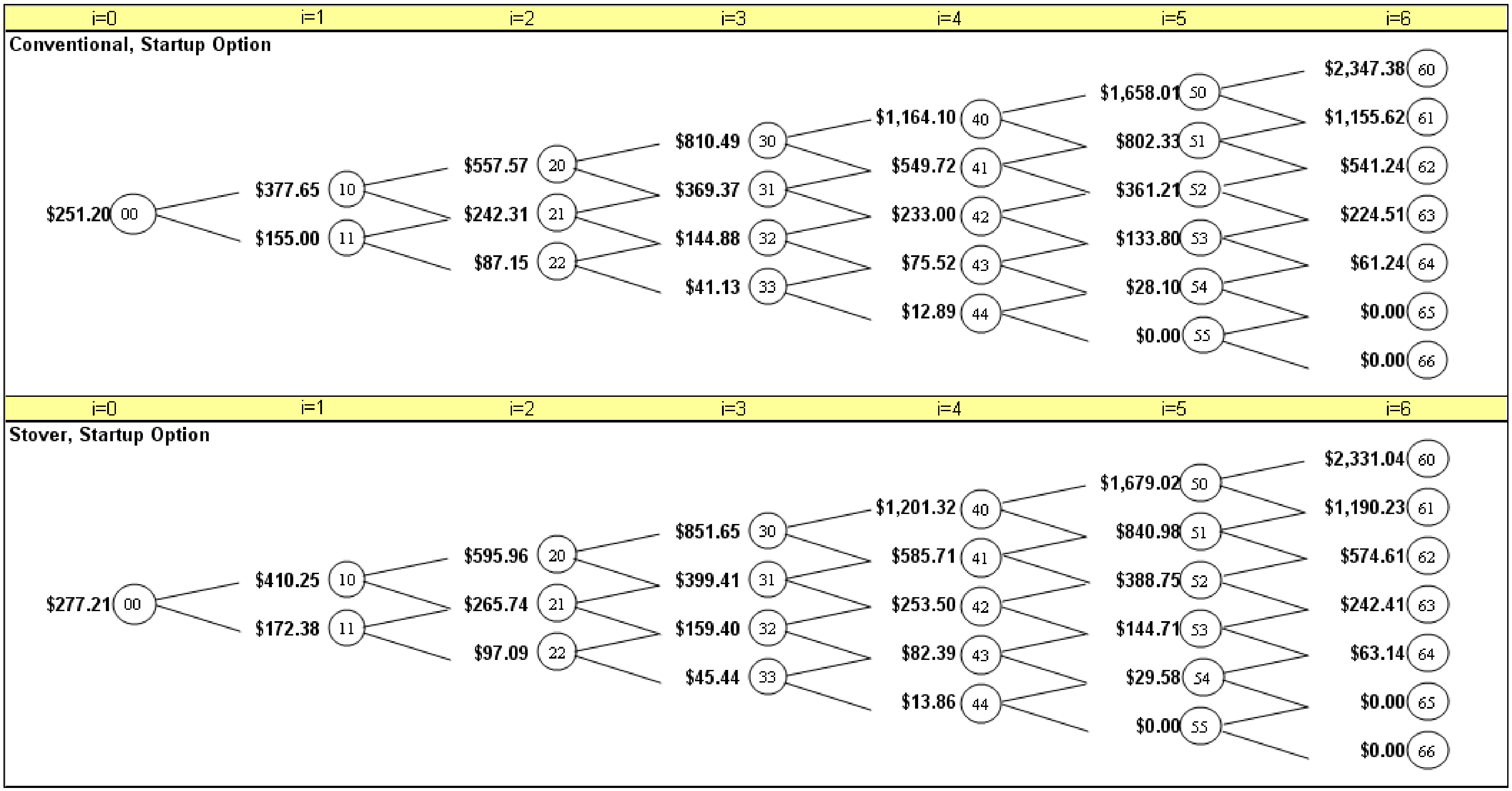


Figure 5.15 Option Values for Conventional Startup and Stover Startup, Separately



It is a different approach of determining the option values for Technology-option 1. Since the option values at each node in the binomial trees in Figure 5.15 have already been discounted by the risk-free return and weighted by the risk-neutral probabilities, we do not have to do the discounting and weighting once again to determine the Technology-option 1. As a matter of fact, because the values of risk-neutral probability for the two types of plants are different, we cannot calculate the value of the expression $R_f^{-1}(p_u C_{i+1,u} + p_d C_{i+1,d})$ in equation 3.21.

Let CC_{ij} denote the option value of the conventional plant at node C_{ij} and CS_{ij} denote the option value of the stover plant at node S_{ij}, then the option value of choosing conventional versus stover CSC_{ij} (***i*** = 0, 1, 2, …, 6 and ***j*** = 0, 1, 2, …, 6) is determined by

$$CSC_{ij} = Max\{CC_{ij}, CS_{ij}\} \qquad (5.6)$$

To determine the strategy at node ***ij***, we compare the NPV of the conventional plant (denoted by NPV_C_{ij}) and the NPV of the stover plant (denoted by NPV_S_{ij}) if at least one of these two is positive. If both NPVs are negative, then we compare the value of waiting and zero to decide whether it is worth waiting or not. The strategies at node ***ij*** are determined by

(1) If $NPV\_C_{ij} > NPV\_S_{ij}$ and NPV_C_{ij} >0, then the strategy at node ***ij*** is to invest for a conventional plant ("Conventional");

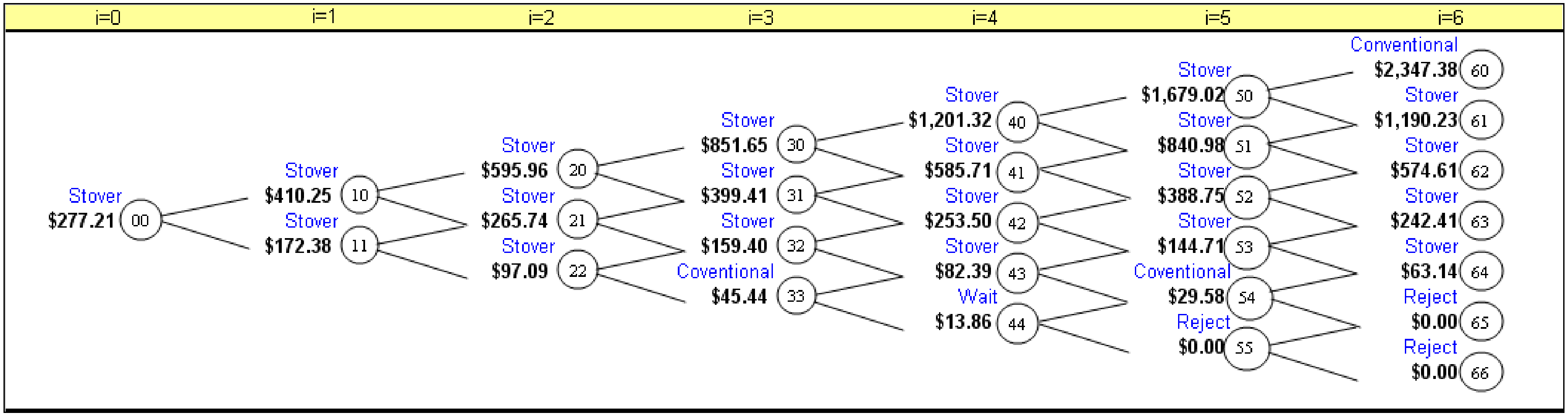
(2) If $NPV\_S_{ij} > NPV\_C_{ij}$ and NPV_S_{ij} >0, then the strategy at node ***ij*** is to invest for a stover plant ("Stover");

(3) If $CSC_{ij} = Max\{CC_{ij}, CS_{ij}\} \neq NPV\_C_{ij}$, and $CSC_{ij} = Max\{CC_{ij}, CS_{ij}\} \neq NPV\_S_{ij}$, and CSC_{ij} >0, then the strategy at node ***ij*** is to wait until next period ("Wait");

(4) If $CSC_{ij} = 0$, then the strategy at node ***ij*** is to reject the project forever ("Reject").

The option values and strategies for Technology-option 1 are given in Figure 5.16.

Figure 5.16 Option Values and Strategies for Technology-option 1



For examples, at node 53, the strategy is to invest for a stover plant. This is because the net present value of the stover plant at node 53 NPV_S_{53} is positive and it is larger than that of the conventional plant at the same node, NPV_C_{53}. From Figure 5.14, we know that NPV_S_{53} = $129.47 million and NPV_C_{53} = $139.06 million. While at node 54, we can see from Figure 5.14 that NPV_S_{54} = $7.37 million, which is smaller than the NPV of the stover plant at the same node NPV_C_{54} = $12.24 million. Therefore, the strategy at node 54 is to invest for a conventional plant.

At node 55, the strategy is to reject both investments forever. This is because the option values for both investments are zero (Figure 5.15) and the NPV for both projects are negative (Figure 5.14). At node 44, the strategy is to wait until next period. This is because the NPVs of both plants are negative. We can see from Figure 5.14 that NPV_C_{44} = -$22.94 million and NPV_S_{43} = -$33.60 million. However, if we look at the option value at node 44 in Figure 5.15, we find that both option values are positive, and CC_{44} = $13.53 million and CS_{44} = $12.41 million. According to the maximization function in (5.6), CSC_{44} = $13.53 million. Furthermore, we can suggest the investor at node 44 to have the construction team to prepare for a conventional plant in the next period.

5.3 The Option to Choose a Conventional Plant versus a Stover-plus Plant

In this section, we compare the investment for a conventional plant versus the investment for a stover-plus plant. We already know from Chapter 4 that the advantages of the latter investment include lower construction cost compared with a stover plant and lower energy cost compared with both the conventional and the stover plant. However, the option values may not reconcile the intuitions. We name this option as Technology-option 2. We will apply the volatility 33.13% to the conventional plant as we did in section 5.2 and apply volatility 31.38% to the stover-plus plant. The comparison for parameters in the BOPM for conventional versus stover are given in Table 5.2.

Table 5.2 Comparison for Parameters, Conventional versus Stover-plus

	Conventional	Stover-plus	Unit
Nameplate	50	50	mm gpy
S, Plant Life	15	15	Years
Initial Investment	\$112.50	\$136.50	Million
E(DCF)	\$16.88	\$20.48	Million
E(CFG)	\$0.59	\$0.66	\$/gallon
E(CF)	\$29.47	\$33.16	Million
rf, risk-free rate	0.04	0.04	
R=1+rf	1.04	1.04	
R^{-1}=1/(1+rf)	0.96	0.96	
T, viability	6	6	years
D**t, time interval**	1	1	years
σ, volatility	33.13%	38.44%	
u, up factor	1.38	1.47	
d, down factor	0.72	0.68	
pu, prob-up	47.72%	45.58%	
pd, prob-down	52.28%	54.42%	

By equation 4.9, the expected initial present value of the stover-plus asset is

$$\left(\frac{\$33.16}{1.04}+\frac{\$33.16}{1.04^{2}}+\frac{\$33.16}{1.04^{3}}+...+\frac{\$33.16}{1.04^{14}}+\frac{\$33.16}{1.04^{15}}\right)+\frac{\$20.48}{1.04^{15}}=\$380.01 \text{ million}$$

Using equation 5.1, we can establish the binomial trees of asset values under volatility for the conventional and the stover-plus, respectively. The comparison of these two binomial trees is given in Figure 5.17. By equation 5.3, the binomial trees of NPVs for both plants are given in Figure 5.18.

Figure 5.17 Asset Values for Conventional versus Stover-plus

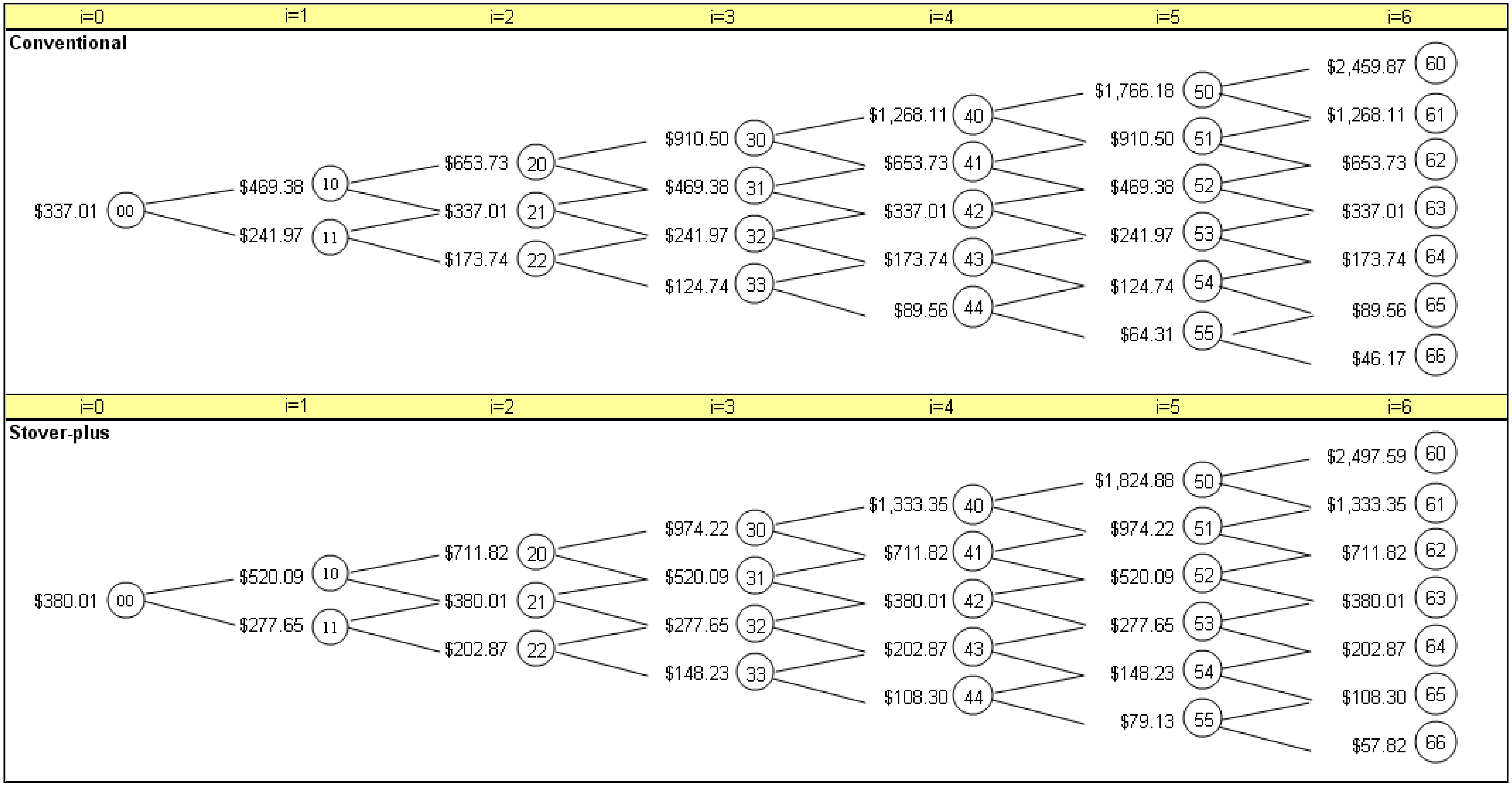
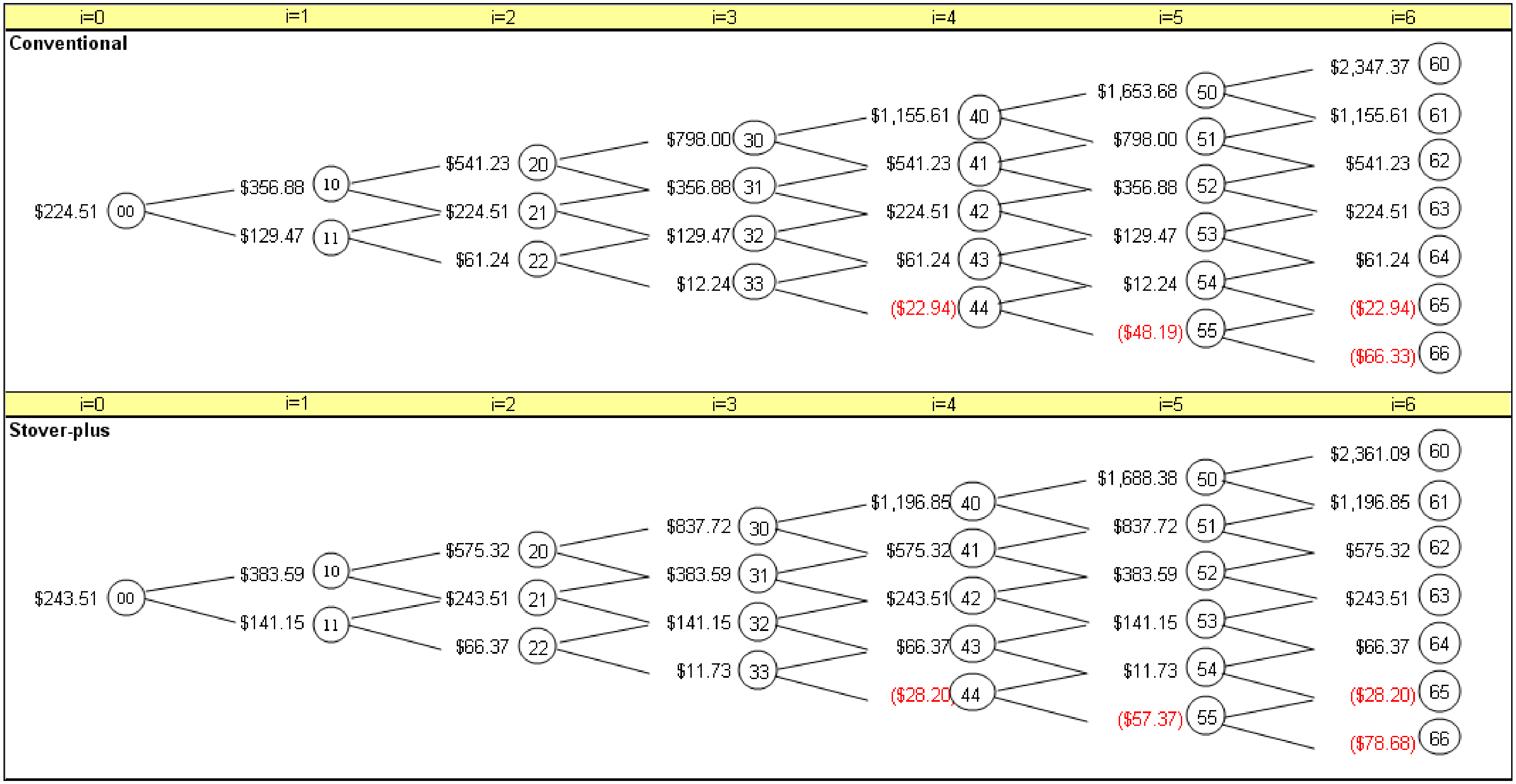


Figure 5.18 Net Present Values for Conventional versus Stover-plus



In Figures 5.17 we can see that the PVs of the stover-plus asset exceed that of the conventional asset at some nodes, for examples, nodes 11, 22, 32, and 43. At the same nodes in Figure 5.18, however, we can see that the NPVs of the conventional asset exceed that of the stover-plus asset. This is because the exercise price for a stover-plus plant is higher than that of a conventional plant.

Similarly as we did for Technology-option 1, we first establish the binomial trees of the option to start a new conventional plant and the option to start a new stover-plus plant. The binomial trees for these two startup options are given in Figure 5.19. Then we can determine the option values for Technology-option 2. The binomial tree for the option values and strategies is given in Figure 5.20.

Figure 5.19 Option Values for Conventional Startup and Stover-plus Startup, Separately

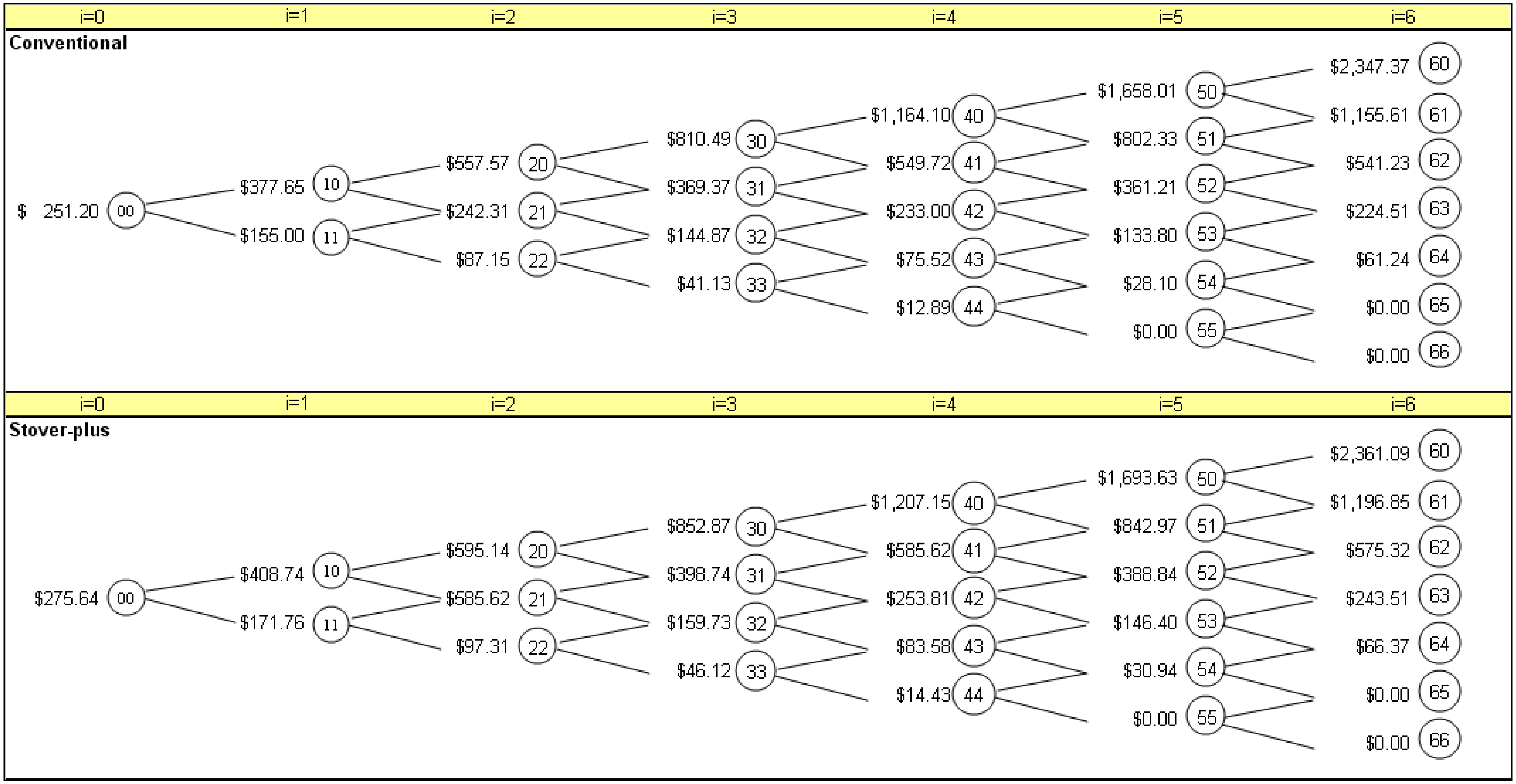
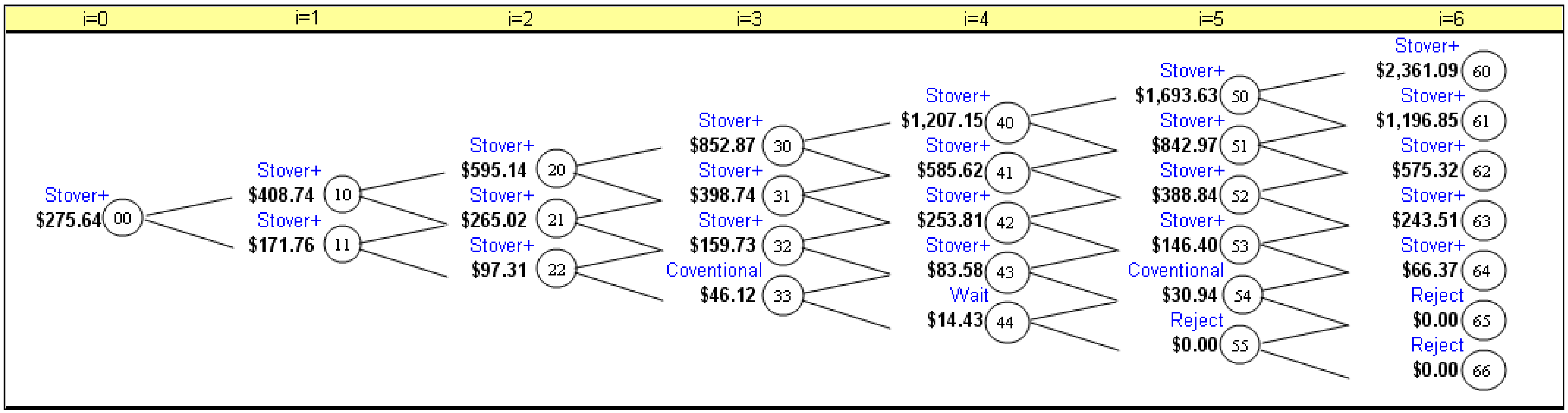


Figure 5.20 Option Values and Strategies for Technology-option 2



Chapter 6 Conclusions

6.1 Conclusions

The analysis in this paper incorporates the net present value method and real options approach for evaluating investments in ethanol facilities. The binomial option pricing model is one of the methods for real options analysis. To establish the binomial option pricing model, we use the net present value method to determine the initial asset value (that is, initial present value of the expected cash flow from the project). Generally, the binomial option pricing model shows that when assuming existence of volatility, the different outcomes for present values at each period can be observed and the corresponding option values for each outcome can be estimated. In this paper, the potential risks are incorporated as volatility and the value of flexibility is analyzed for the investment decisions.

The objectives for this research are to identify the uncertainty in ethanol investments, to identify the applicable real options for dry-milling ethanol plants, to make recommendations and suggestions for ethanol investors, and to give recommendations for why real options analysis may be useful. The four objectives have been achieved by this paper and we will discuss the results for each objective in the following.

First, the volatility in our model provides identification and estimation for the key price uncertainty in the ethanol industry. We use historical ethanol price, corn price, and fuel price as variables when generating historical cash flows. These prices contribute a significant proportion in cash flows for a dry-milling ethanol plant. Based on previous studies, other prices and costs were found to be less significant in affecting the cash flows, so we assume these as constants in calculations for the cash flows. Distributions are fitted to the generated historical cash flows, and we use these distributions to simulate annual cash flow series for calculating the present values. Given insufficient historical plant-level data for calculating present values for volatility, we use simulated cash flows to calculate the present values. The volatility of the present values for a given technology is then estimated. Therefore, when we use this model, we know that the volatility reflects the key price uncertainty for current dry-milling ethanol plants. While other factors may affect the variability of present values, these are not analyzed and we have a focus on the effects by the key price factors.

Second, the applicable real options are also identified in this paper. Recall that a real option is the right but not the obligation to exercise a certain action (accept, reject, wait, or abandon) in an investment. For ethanol facilities investment in our analysis, the applicable real options include (1) the option to expand a conventional ethanol plant, (2) the option to start a conventional plant or a stover plant, and (3) the option to start a conventional plant or a stover-plus plant. We chose to focus on these options based on the development of the U.S. ethanol industry today. Most of the ethanol plants are using corn as the feedstock and dry-milling as the base processing technology. With the increasing demand for ethanol, it is reasonable that most of the owners will have options to expand based on the same technology. Hence, we evaluate the option to expand for a medium-sized conventional ethanol plant as well as the scenario analysis for different combinations of volatility levels and initial present values. Emerging technologies also provide options for ethanol investors who intend to lower the energy costs from using natural gas for corn-based dry-milling ethanol plants. In our analysis, we discuss the option to start a dry-milling ethanol plant using corn stover as boiler fuel instead of natural gas, and compare it with the option to start a conventional dry-milling ethanol plant which uses natural gas as the boiler fuel. We also discuss the option to start a dry-milling ethanol plant using the combination of stover and corn syrup as boiler fuel, and compare it with the option to start a conventional ethanol plant. These options are applicable for ethanol investors today in terms of capital requirements and the availability of technology.

Third, the results in our analysis ensure more flexibility in investment decisions for ethanol investors. For example, when going further into the future periods of a binomial tree, more than one outcome of the present value are estimated. For each out come, the corresponding option value is also evaluated and the strategy is given. These strategies actually provide an index for evaluating the overall situation of a given option. A simple way is just to observe the strategy at each node in a binomial tree and count the number of the same strategies. If more of the strategies in a binomial tree are to reject the project than to accept or to wait, we may conclude that the option will not be favored by the investor. Next, we will discuss the results for each option evaluated in our model.

The option of expanding the production for a conventional plant is measured under three different scenarios. These scenarios have different levels of volatility for present values and different initial values for the binomial tree of present values. We do the scenarios analysis because different subperiods generate different historical cash flows. We are interested to know if the option values will be affected given that we identify the difference in the subperiods. As the results show, we can fit different distributions to the cash flows in different periods and that lead to different volatility of present values as well as different expected initial present values. The first scenario is based on the generated cash flows from January 2001 to August 2007. The second scenario is based on the subperiod from May 2002 to December 2004. The third scenario is based on the subperiod from January 2005 to August 2007. We can find that in the second scenario, the volatility is higher and the expected initial present value is lower compared to the third scenario. In the binomial tree of the option values for the second scenario, more strategies are suggested to wait instead of expand. With higher volatility, the proportional changes in both positive and negative net present values (recall that net present value is present value minus exercise price) are higher, and the option values are also higher enough to ensure a positive value of waiting.

The results of the two Technology-options support the stover-based combustion technology. When comparing the option to start a conventional plant and the option to start a stover plant (Technology-option I), we can find that more of the strategies in the binomial tree are to choose the stover plant but not the conventional plant. This means that at a given node, the net present value of the stover plant exceeds that of the conventional plant. However, this is not always the case. At some nodes, the net present values of the conventional plant exceed that of the stover plant, so the conventional plant is chosen over the stover plant. If an investor only looks at the initial net present values of these two plants by net present value method, she may easily choose the stover plant over the conventional plant, while ignoring the risks of having unexpected lower net present value for the stover plant in the future (when compared to that for the conventional plant).

For the option to choose a stover-plus versus a conventional technology (technology-option II), the volatility of present value for the stover-plus plant is about the same as that for the stover plant. However, the initial present value of a stover-plus plant is the highest one among the three plant types. In the binomial tree of option values, we find that the stover-plus technology is chosen more frequently than conventional plant, but when the net present values for both plants keep decreasing, the conventional is suggested to be chosen over the stover-plus plant at some nodes. This once again shows the importance of using binomial option pricing model to observe the change of net present values in the future.

Finally, from all the results we have, we can see the importance of applying real options analysis to investment decisions in ethanol industry. Real option analysis provides a method for incorporating uncertainty into the evaluation of investment projects. That is, we estimate and use volatility to establish binomial trees for present values and option values. Real options analysis gives results for evaluating the project, as well as the choice among competing decisions, such as waiting, rejecting, or accepting the project. In another word, the managerial flexibility is quantified by real options analysis. Investors can assess how the present value will change under uncertainty in the future and how the value of her action is affected by responding to the changes in the future. This will help investors to make decisions more efficiently and with more flexibility.

6.2 Future Study

Both the results from our scenario analysis and the results from evaluating the Technology-options show that the initial present values and the volatility level matter. For a given technology, the initial present value is calculated using the expectation of cash flows from the fitted distribution. Because for each type of technology, @Risk fits several different distributions to the generated historical cash flows and by different distributions, we can have different expectations for cash flows. Consequently, the choice of fitted distributions affects the initial present value for establishing the binomial tree. It also affects the calculation for volatility of present values, because we simulate random values for cash flows from the chosen distribution and then use these simulated cash flow values to calculate the present values and its volatility.

In @Risk, the fitted distributions are ranked by Chi-square values. The lower the Chi-square value is, the more confident we are to believe the distribution fits better to the data. The distributions chosen for our analysis are all normal distributions. However, by the ranking of chi-square values in @Risk, normal distributions fit reasonably well but they are not necessarily the best fitted distributions to the generated cash flows. Thus in our model application, we sacrifice the goodness-of-fit for the ease of explanation. Further study may want to consider the best fitted distributions by @Risk.

In previous studies, the level of volatility can significantly affect the investment decisions. In sensitivity analysis, a single-variable is allowed to change while holding all other parameters as constant. We have not done sensitivity analysis. Rather, we perform a scenario analysis for the expansion option, which allows the volatility and the initial present value to vary at the same time. Using the scenario analysis, we cannot observe the effects on the option values by changing volatility levels only. However, the scenario analysis speaks well for the different periods in history, since in history, it is usually that several variables are varying at the same time.

Appendix A. Estimating Cash Flows and Present Values

In our analysis, we use Monte Carlo simulation (MCS) to simulate cash flows. MCS is an approach used to model the uncertainty in many areas, such as physics, mathematics, finance, etc. It incorporates the uncertainty into the projection of the future values of a variable that we are interested in. Note that if we have sufficient historical data for a certain variable, we probably do not need MCS to estimate the uncertainty. Instead, we can use the historical data directly to do a reliable estimation for the volatility. Firstly, to do MCS, we use historical values of a variable to specify a distribution of this variable. Secondly, we make random draws from the specified distribution. Usually, we let computer to finish this task. In the software @Risk, the minimum number of iterations for making random draws from a distribution is 100. Thirdly, we use the random sample from the distribution to estimate the uncertainty and project the future values. The flow chart in Figure A.1 shows the procedure of how the volatility is derived.

In Chapter 4, we have introduced the equations for calculating cash flows for each type of plant (equations 4.7, 4.14, and 4.17). To make clearer of how the coefficients and constant terms in these equations are derived, we summarize the efficiency ratio assumptions for all types of plants in Table A.1. An overview of price variables is also given in Table A.2. We know that in step (4) in Figure A.1, the cash flow equations are built by an Income Statement structure.

Figure A.1 Procedure of Estimating Volatility of Present Values

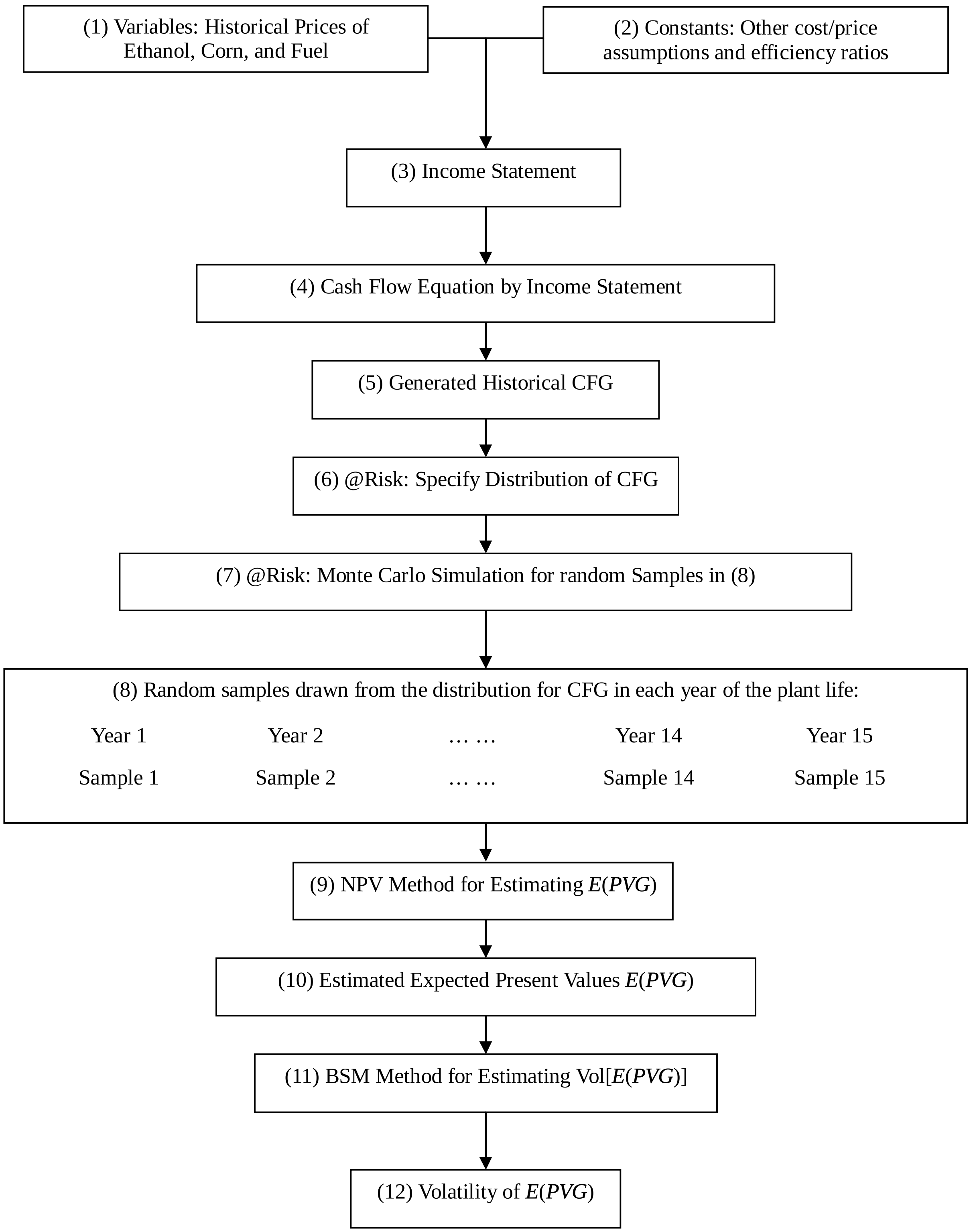


Table A.1 Efficiency Ratios for Conventional, Stover, and Stover-plus

Efficiency Ratios	Unit	Notation*	Conventional	Stover	Stover-plus	Source
DDGS Production	tons/gallon ethanol	$\overline{q}_D$	0.0032	0.0032	0.0019	(1)
Ash Production	tons/gallon ethanol	$\overline{q}_A$	N/A	0.00016	0.00021	(1)
Corn Consumption	bushesl/gallon ethanol	$\overline{q}_C$	0.3509	0.3509	0.3509	(2)
Natural Gas Consumption	mmbtu/gallon ethanol	$\overline{q}_N$	0.035	N/A	N/A	(3)
Corn Stover Consumption	tons/gallon ethanol	$\overline{q}_S$	N/A	0.0026	0.0009	(1)
Electricity Consumption	kwhs/gallon ethanol	$\overline{q}_{El}$	0.75	0.95	0.95	(1)
Denaturant Consumption	gallons/gallon ethanol	$\overline{q}_{De}$	0.05	0.05	0.05	(2)
Ammonia Consumption	tons/gallon ethanol	$\overline{q}_{Am}$	N/A	0.000007	0.000004	(1)
Limestone Consumption	tons/gallon ethanol	$\overline{q}_{Li}$	N/A	N/A	0.000075	(1)
Prices						
Ethanol	$/gallon	$\tilde{P}_E$	Variable	Variable	Variable	(4)
Corn	$/bushel	$\tilde{P}_C$	Variable	Variable	Variable	(5)
Natural Gas	$/mmbtu	$\tilde{P}_N$	Variable	N/A	N/A	(6)
Stover	$/dry ton	$\tilde{P}_S$	N/A	Variable	Variable	(7)
DDGS	$/ton	$\overline{P}_D$	92.85	92.85	92.85	(3)
Ash	$/ton	$\overline{P}_A$	N/A	200.00	200.00	(1)
Electricity	$/kwhs	$\overline{P}_{El}$	0.05	0.05	0.05	(2)
Denaturant	$/gallon	$\overline{P}_{De}$	1.50	1.50	1.50	(2)
Ammonia	$/ton	$\overline{P}_{Am}$	N/A	500.00	500.00	(1)
Limestone	$/ton	$\overline{P}_{Li}$	N/A	N/A	25.00	(1)
Other COGS and Expenses						
Chemicals, Enzymes & Yeast	$/gal ethl	$\overline{c}_{Ch}$	0.06	0.06	0.06	(2)
Water and Waste	$/gal ethl	$\overline{c}_{Wa}$	0.005	0.005	0.005	(2)
Operating Expenses **	$/gal ethl	$\overline{c}_{OE}$	0.15	0.15	0.15	(2)
Interest Expense ***	$/gal ethl	$\overline{c}_{IE}$	0.0396	0.0517	0.0480	(2)
Depreciation & Amortization	$/gal ethl	$\overline{c}_{DA}$	0.1275	0.1849	0.1717	(1)
Construction Cost	$/gal ethl	$\overline{c}_{CO}$	2.25	2.94	2.73	(1)
Disposal Cash Flow	$/gal ethl	$DCFG$	0.3375	0.4410	0.4095	(2)

***** The notations in this table are generalized notations. For different technology, the subscript of some notations may vary. For example, the Interest Expenses $\overline{c}_{IE}$ for the three plants vary. We use $\overline{c}_{IE-C}$ to denote the Interest Expense for conventional plant, $\overline{c}_{IE-S}$ to denote the Interest Expense for stover plant, and $\overline{c}_{IE-P}$ to denote the Interest Expense for stover-plus plant.

****** Operating Expenses include: Supplies, Maintenance & Repairs, Production Labor, Insurance, Administrative Expenses, Management Fees, Marketing Expenses, Real Estate Taxes, Other Taxes, Other Costs / Miscellaneous. $0.15/gallon is an approximation of the benchmark reported by Christianson & Associates, 2004-2005.

******* Interest expense is calculated by the 1.5 debt-to-equity ratio and averaged at a 15-year debt schedule.

(1) De Kam, Morey, and Tiffany, "Integrating Biomass for Electricity and Process Heat at Ethanol Plants", 2007
(2) Author's calculation as an approximation of the benchmark reported by Christianson & Associates, 2004-2005
(3) USDA, "Ethanol Cost of Production", 2002
(4) Omaha F.O.B. monthly price, 1/1/2001-8/1/2007
(5) Chicago monthly market price reported by USDA, 1/1/2001-8/1/2007
(6) Industrial monthly price reported by USE, 1/1/2001-8/1/2007
(7) We assume that the stover price follows a lognormal distribution. The expectation of stover price is $52/dry ton and the standard deviation of stover price is $11/dry ton. This assumption was initially made by Petrolia (2006).

Table A.2 The First and Last 10 observations of Historical Prices and Generated Cash Flows

obs	Date	Ethanol Price	Corn Price	Natural Gas Price	Corn Stover Price*	CFG (Conventional)	CFG (Stover)	CFG (Stover-plus)
1	1/1/2001	$1.77	$2.03	$8.73	$41.23	$0.6822	$0.8869	$0.8490
2	2/1/2001	$1.70	$1.99	$7.12	$45.35	$0.6826	$0.8202	$0.7893
3	3/1/2001	$1.51	$2.07	$6.22	$67.01	$0.4960	$0.5458	$0.5517
4	4/1/2001	$1.46	$2.04	$6.00	$53.78	$0.4641	$0.5407	$0.5242
5	5/1/2001	$1.76	$1.96	$5.39	$57.59	$0.8136	$0.8589	$0.8488
6	6/1/2001	$1.63	$1.89	$4.69	$45.30	$0.7327	$0.7854	$0.7544
7	7/1/2001	$1.41	$2.07	$4.05	$62.26	$0.4720	$0.4582	$0.4560
8	8/1/2001	$1.49	$2.13	$3.94	$46.40	$0.5347	$0.5583	$0.5292
9	9/1/2001	$1.53	$2.10	$3.46	$57.72	$0.6022	$0.5794	$0.5696
10	10/1/2001	$1.36	$1.98	$3.14	$52.56	$0.4853	$0.4650	$0.4463
M	M	M	M	M	M	M	M	M
M	M	M	M	M	M	M	M	M
71	11/1/2006	$2.25	$3.51	$7.69	$52.19	$0.6809	$0.8208	$0.8015
72	12/1/2006	$2.43	$3.60	$8.15	$55.94	$0.8114	$0.9577	$0.9448
73	1/1/2007	$2.26	$3.78	$7.27	$51.76	$0.6093	$0.7354	$0.7154
74	2/1/2007	$2.12	$3.96	$8.27	$53.07	$0.3710	$0.5289	$0.5111
75	3/1/2007	$2.31	$3.92	$8.47	$62.06	$0.5680	$0.7095	$0.7070
76	4/1/2007	$2.37	$3.56	$8.17	$72.98	$0.7648	$0.8674	$0.8835
77	5/1/2007	$2.46	$3.75	$8.14	$54.23	$0.7892	$0.9395	$0.9237
78	6/1/2007	$2.43	$3.82	$8.01	$47.58	$0.7392	$0.9023	$0.8751
79	7/1/2007	$2.51	$3.19	$7.58	$55.34	$1.0553	$1.1831	$1.1692
80	8/1/2007	$2.43	$3.30	$6.58	$42.87	$0.9717	$1.0970	$1.0619

* The prices for corn stover is a random sample from the Lognormal distribution with mean $52.00/dry ton and standard deviation $11.00/dry ton. The assumption for the distribution is by Petrolia (2007) in his study for corn stover costs.

Appendix B. Black-Scholes-Merton's Method for Estimating Historical Volatility

The Black-Scholes-Merton's (BSM) method was introduced by Fisher Black, Myron Scholes, and Robert Merton in early 1970's for pricing of stock options. The price of a non-dividend-paying stock is usually assumed to follow a stochastic process. BSM assumes that percentage changes in the stock price in a short period of time are normally distributed and the stock price itself has a lognormal distribution. The lognormal property of stock prices can be used to provide information on the probability distribution of the continuously compounded rate of return earned on a stock between times 0 and *T*. By Black-Scholes method, volatility is defined as the standard deviation of the logarithm of change in stock price:

$$vol(S) = SD(\vec{u}) \qquad \text{(B.1)}$$

where $\vec{u} = \{u_1, u_2, ..., u_i, ..., u_T\} = \{\ln(S_1 / S_0), \ln(S_2 / S_1), ..., \ln(S_i / S_{i-1}), ..., \ln(S_T / S_{T-1})\}$ and SD means standard deviation. The standard deviation of $\vec{u}$ is given by

$$SD(\vec{u}) = \sqrt{\frac{\sum_{i=1}^{T}(u_i - \bar{u})^2}{T}} \qquad \text{(B.2)}$$

where $\bar{u}$ is the sample mean of $\vec{u}$ and T is the total counts of observations of $\vec{u}$, or, the sample size of $\vec{u}$.

An example of calculating the historical volatility of stock price is given in Table **B.1**. The sample mean $\bar{u}$ equals 0.0048 and the difference between each observed value u_i and $\bar{u}$ is given in the last column of the table. The sum of the squared differences $\sum_{i=1}^{T}(u_i - \bar{u})^2$ = 0.0028. So by BSM method, the volatility of the stock price from day 0 to day 20 is $\sqrt{0.0028/20} = 1.19\%$. To estimate the volatility of the ethanol assets, we use @Risk to simulate historical cash flows (CFs) and calculate the corresponding present values (PVs). Then we use BSM method to calculate the volatility of PVs. In the next Appendix, we will introduce how @Risk uses Monte Carlo Simulation to estimate the historical distribution of CFs and how we simulate the PVs based on the estimated distributions of CFs.

Table B.1 Calculation for Volatility of Stock Price

Day	Closing Stock Price (dollars)	Price relative Si/Si-1	Daily return ui=ln(Si/Si-1)	Difference $u_i - \bar{u}$
0	20.00			
1	20.10	1.0050	0.0050	0.0002
2	19.90	0.9901	-0.0100	-0.0148
3	20.00	1.0050	0.0050	0.0002
4	20.50	1.0250	0.0247	0.0199
5	20.25	0.9878	-0.0123	-0.0170
6	20.90	1.0321	0.0316	0.0268
7	20.90	1.0000	0.0000	-0.0048
8	20.90	1.0000	0.0000	-0.0048
9	20.75	0.9928	-0.0072	-0.0120
10	20.75	1.0000	0.0000	-0.0048
11	21.00	1.0121	0.0120	0.0072
12	21.10	1.0048	0.0048	0.0000
13	20.90	0.9905	-0.0095	-0.0143
14	20.90	1.0000	0.0000	-0.0048
15	21.25	1.0168	0.0166	0.0118
16	21.40	1.0071	0.0070	0.0023
17	21.40	1.0000	0.0000	-0.0048
18	21.25	0.9930	-0.0070	-0.0118
19	21.75	1.0235	0.0233	0.0185
20	22.00	1.0115	0.0114	0.0067

Source: Table 13.1 (John C. Hull, *Options, Futures, and Other Derivatives* (2007), page 287)

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