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QUANTITY AND CAPACITY EXPANSION DECISIONS FOR ETHANOL IN NEBRASKA AND A MEDIUM SIZED PLANT

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by

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QUANTITY AND CAPACITY EXPANSION DECISIONS

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Corn-based ethanol is the leader of sustainable sources of energy in the United States due to the abundance of corn and the popularity of ethanol-gasoline mixes. Over the past decade, ethanol production has risen from 1.5 million gallons in 1999 to 13 million gallons in 2011. This increase in production requires expansion of ethanol plants. Since Nebraska is the second highest producer of ethanol, we focus our research on the expansion of ethanol plants in Nebraska.

The aim of this study is to develop an optimization model for capital investments in ethanol in Nebraska and a medium sized ethanol plant with 100 million gallons capacity in 2011. The model is developed for a firm in Nebraska and uses a planning horizon of five years. The problem is formulated as a dynamic programming model and solved using spread sheets. The data used are gathered from published papers, USDA reports, official Nebraska government website and Renewable Fuel Association reports (RFA). We find that the best strategy for a medium sized plant with capacity of 100 million gallons is to expand the capacity by 50 million gallons in the first year and reject the decision to expand in the following years up to 2016. The best expansion for ethanol in Nebraska is 200, 100 and 100 million gallon for 2012, 2013 and 2014 respectively and no expansion in 2015 and 2016. A scenario analysis is used to illuminate the decision space for different scenarios of profit margin and ethanol demand fluctuations.

Keywords: Ethanol, corn, dynamic programming, capacity expansion.

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1. Introduction

1.1. Growing interest in ethanol

The United States has been a net importer of ethanol in the last decade. The imported ethanol is blended with gasoline and used for transportation fuel. In 2008, 556 million gallons of ethanol were imported, worth $1.25 billion. But in 2010 the United States produced 13.2 billion gallons of ethanol. It was enough to meet the U.S demand of 12 billion gallons and have revenue of $825 million from export. In other words, in 2010 the United States became the global low-cost ethanol producer (USDA [1] International agricultural trade report, July 20, 2011). The capacity of the U.S ethanol production is still increasing. The factors that increase the interest in ethanol production in the U.S are increasing crude oil prices, climate change concerns, elimination of Methyl Tertiary Butyl Ether (MTBE), and stimulating American economy.

1.2. Factors increasing interest in ethanol

Figure1-1 shows the price of crude oil versus its production in the past few years. The figure shows an increasing trend of the oil price. Even with the higher production in 2012 and with growing production, crude oil production has not been sufficient to bring oil prices back to the $60 a barrel or less range that we were comfortable with prior to 2006. According to EIA[2] data, crude oil production in 2005 averaged 73.6 million barrels a day. It has grown very little since then. Crude oil production for 2011 averaged 74.0

[1] United States Department of Agriculture
[2] U.S Energy Information Administration

million barrels a day. Prices for crude oil are assumed to remain historically high over the next decade.

Figure 1-1 Crude oil production vs Brent oil spot price, in US $

Source: U.S. Energy Information Administration/Petroleum Marketing Monthly February 2012.

The second reason of increasing interest in ethanol is the climate change concern. Ethanol is one of the tools to fight air pollution from vehicles. It can improve overall environmental quality compared to gasoline. Because it is made from plant-based feed stuck, the CO2 released during a vehicle's fuel combustion is "recycled" during the growth of ethanol feed stuck. Ethanol reduces GHG[3] emissions by 30% to 50%. A study published by Yale University's Journal of Industrial Ecology states that GHG emissions from ethanol produced at dry-mill facilities are "equivalent to a 48 percent to 59 percent reduction of GHG compared to gasoline." (National Dry Mill Corn Ethanol Survey, May 4, 2010.)

[3] Green House Gas

The next reason that the interest in ethanol is increasing is the concern about national energy security. In 2011, over 60% of crude oil used in the U.S. was imported from other countries. Figure 1-2 shows the reduction of oil imported in the past few years because of domestic ethanol production. For example, in 2004, 143 million barrels of oil was reduced, and in 2011 American ethanol production helped reduce the need for imported oil by 485 million barrels. The figure shows an increasing reduction in the oil imported during the past years. This reduction in the oil import proves the importance of ethanol as a substitute for oil.

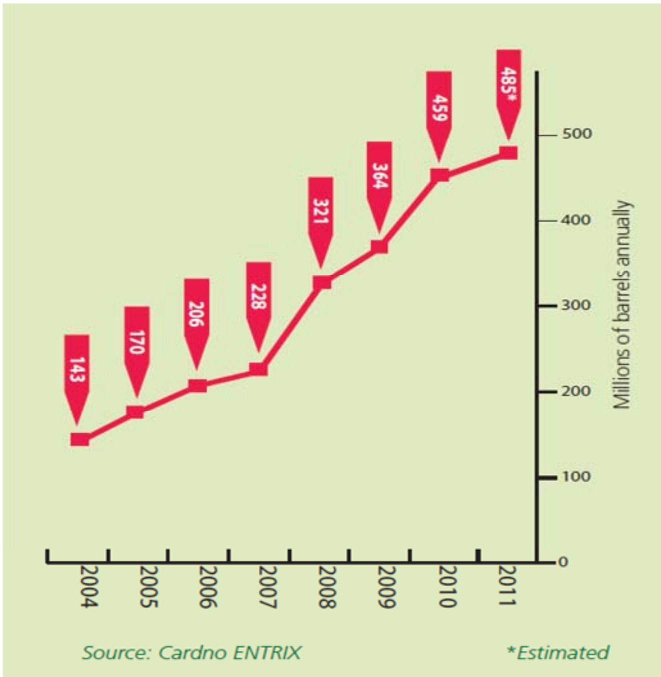


Figure 1-2 Reduction in oil imports in the past few years

Elimination of Methyl Tertiary Butyl Ether (MTBE) also helped to increase the interest in producing ethanol. MTBE is a flammable liquid which is used as an additive in unleaded gasoline. Its use has decreased in the United States in response to environmental and health concerns. It has been banned according to recent state laws in certain areas. In

January 1, 2004 California and New York, which together accounted for 40% of U.S. MTBE consumption, banned the use of MTBE in gasoline. As of September 2005, twenty-five states had signed legislation banning MTBE. Table 1-1 shows the state by state information about the date of banning the MTBE and also the MTBE consumption percentage of U.S total.

Table 1-1 Overview of State Source: MTBE consumption estimates are based on EIA data as of December 2002

State	**MTBE Ban Schedule**	**MTBE Consumption (% of U.S. total)**
California	MTBE ban starting January 1, 2004	31.7
Colorado	MTBE ban started April 30, 2002	0
Connecticut	MTBE ban starting October 1, 2003	3.1
Illinois	MTBE prohibited by July 2004	0
Indiana	MTBE limited to 0.5% by volume, starting July 23, 2004	0
Iowa	0.5% MTBE by volume cap, already in effect	0
Kansas	MTBE limited to 0.5% by volume, starting July 1, 2004	0
Kentucky	MTBE ban starting January 1, 2006; beginning in January 1, 2004, ethanol encouraged to be used in place of MTBE	0.8
Maine	Law merely expresses state's "goal" to ban MTBE; it's not an actual ban. The "goal" is to phase out gasoline or fuel products treated with MTBE by January 1, 2003	0
Michigan	MTBE prohibited by June 1, 2003	0
Minnesota	All ethers (MTBE, ETBE, TAME) limited to 1/3 of 1.0% by weight after July 1, 2000; after July 1, 2005, total ether ban	0
Missouri	MTBE limited to 0.5% by volume, starting July 1, 2005	1.1
Nebraska	MTBE limited to 1.0% by volume, starting July 13, 2000	0
New York	MTBE ban starting January 1, 2004	7.5
Ohio	MTBE ban starting July 1, 2005	0
S. Dakota	0.5% MTBE by volume cap, already in effect	0
Washington	MTBE ban starting December 31, 2003	0

Figure 1-3 shows the U.S. gasoline production in green, the U.S ethanol production in blue, and the increasing line of ethanol production as a percentage of domestic fuel production for gasoline vehicles. The line shows an increasing percentage of ethanol production.

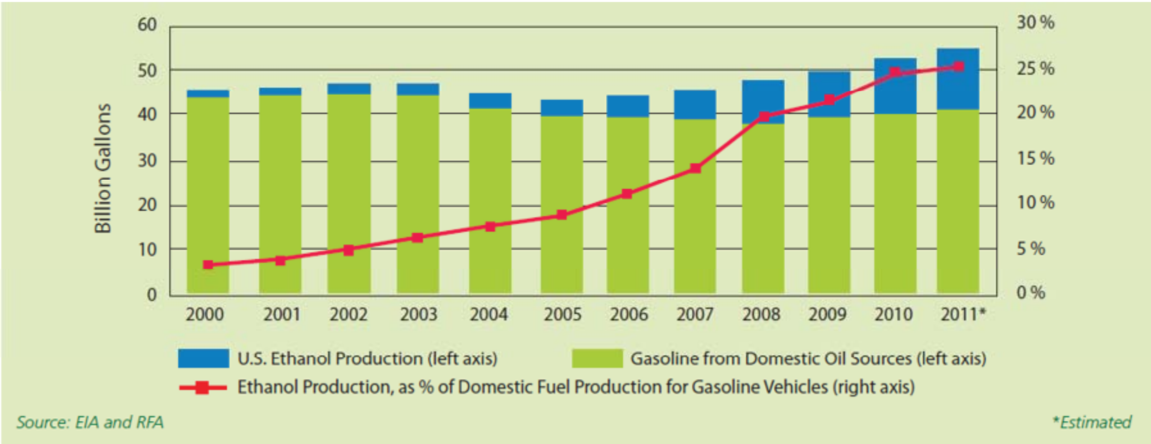


Figure 1-3 Ethanol production as % of domestic fuel

Ethanol has helped to stimulate the American economy. In 2011, 90,200 direct jobs and 311,400 indirect/induced jobs were created. This generated $42.4 billion contribution to GDP and $29.9 billion in household income (Urbanchuk, 2012).

1.3.U.S ethanol industry overview

Table 1-2 shows that the investment in ethanol industry in the U.S. has increased over the past years. In 2001, there were only 56 ethanol plants in the U.S; however, in 2011, the number of ethanol plants increased to more than 200. In year 2011, there are still more than 500 plants under construction which shows the growing interest in ethanol in the nation. In 2011, 29 states produce ethanol compared to only 18 states in 2004. Table 1-2 shows complete information about the ethanol industry in the U.S.

Table 1-2 US ethanol industry overview (RFA, 2012)

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Total Ethanol Plants	56	61	68	72	81	95	110	139	170	189	204
Ethanol Production Capacity (million gallons)	1921.9	2347	2706.8	3100.8	3643.7	4336.4	5493.4	7888.4	10569.4	11877.4	13507.9
Plants under construction /Expansion	5	13	11	15	16	31	76	61	24	15	10
Capacity under construction or expanding (million gallons)	64.7	390.7	483	598	754	1778	5635.5	5536	2066	1432	522
States with eth. plants	18	19	20	19	18	20	21	21	26	26	29

Ethanol production capacity also has expanded during past years. Table 1-2 also shows the production capacity of ethanol in the U.S. In 2001, the capacity of ethanol production in the U.S. was 1921 million gallons, but in 2011 it increased to 13,507 million gallons.

1.4.Corn as an important feed stuck to produce ethanol

Most ethanol production in the U.S. currently uses corn as the feed stuck. Figure 1-4 compares the yearly amount of corn used for feed and residual use, feed stuck to produce ethanol, and exports. It also includes the projection for 2020. According to the figure, corn is increasingly used as a feed stuck for ethanol production with about 36 percent of total corn use expected to go to ethanol production during the projection period. (USDA long term projections report, Feb 2012).

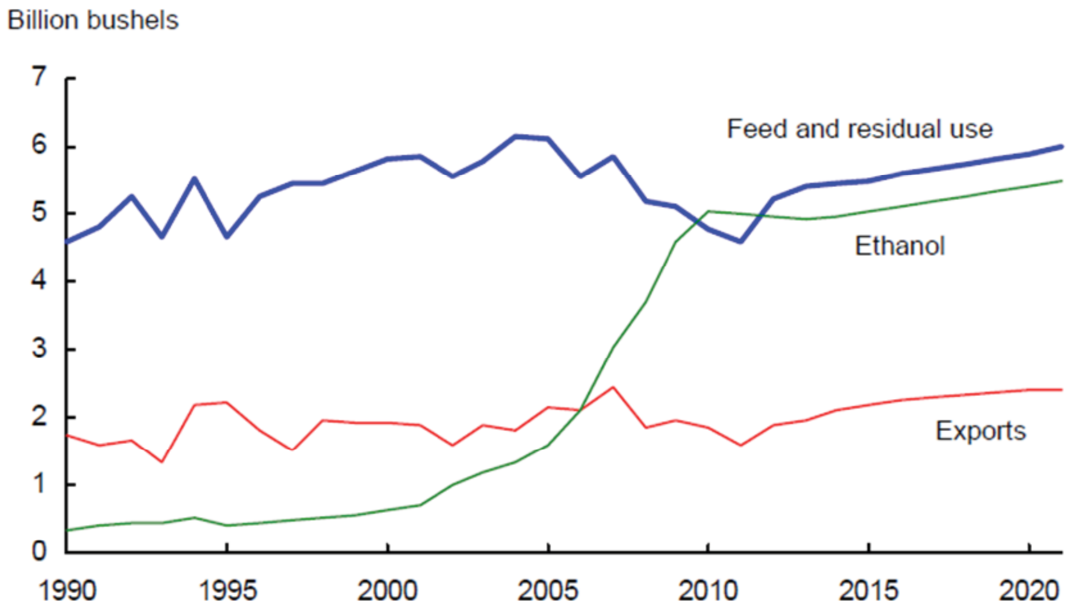


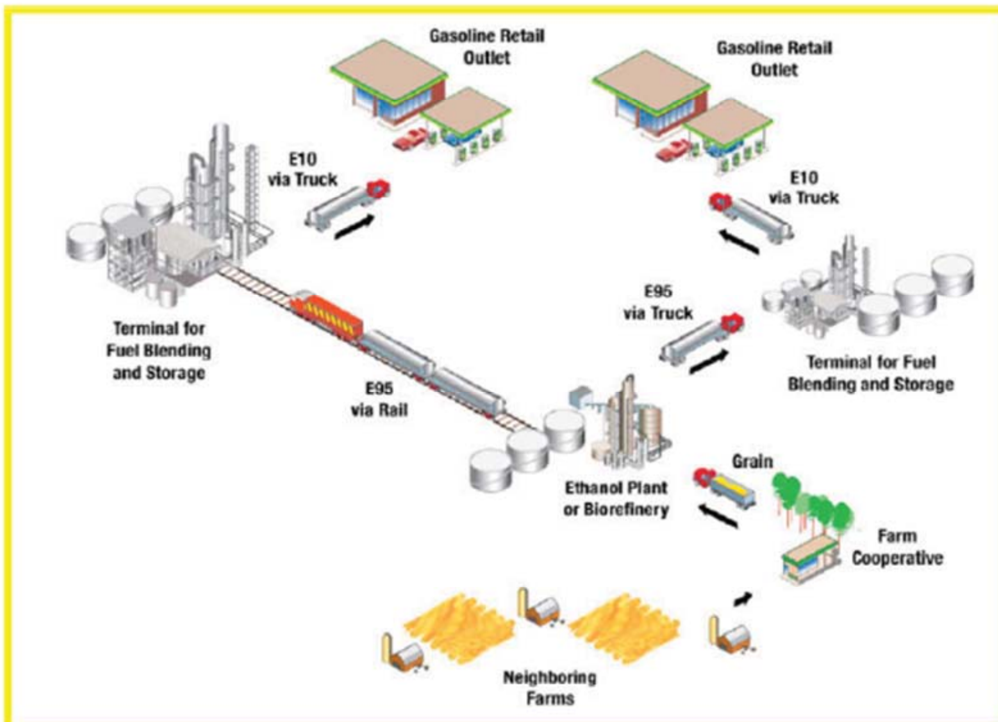
Figure 1-4 U.S. corn use (USDA Long-term Projections, February 2012)

1.5.Corn-ethanol supply chain

Figure 1-5 shows the corn ethanol supply chain. Ethanol supply chain starts from farms and ends at the gasoline retail outlets. Needed corn is provided from neighboring farms to the plants, and then ethanol is produced in the plants. It will be then transferred via rail or trucks to the terminals for fuel blending and storage, and final product, E10 [and/or E85][4], is distributed to the gasoline retail outlets via trucks at the end. Studying the ethanol supply chain requires a good understanding of all the parts of the chain and their relationships and interactions. For example, production level of an ethanol plant is

[4] E85 is 85% ethanol and 15% gasoline and E10 is 10% ethanol and 90% gasoline.

related to the harvest amount of corn in the farms and also ethanol demand in the gasoline retail outlets. Although working on the whole supply chain is worthwhile, our project scope is limited to study the production level and capacity expansion in Nebraska Plants and particularly a single medium sized plant in Nebraska.



Source: US Department of Agriculture, 2007.

Figure 1-5 Corn-ethanol supply chain

1.6.Ethanol industry in Nebraska

State of Nebraska is the second highest producer of ethanol in the U.S. (Figure 1-6). Nebraska produces 14% of the total ethanol in the nation. It has 25 active ethanol plants with an operating production of 1964 million gallons per year. This level of production requires 818 million bushels of grains per year. The current investment in the ethanol plants in Nebraska is more than $5 billion which provide 1200 job opportunities. Figure 1-7 shows the plant locations throughout the state.

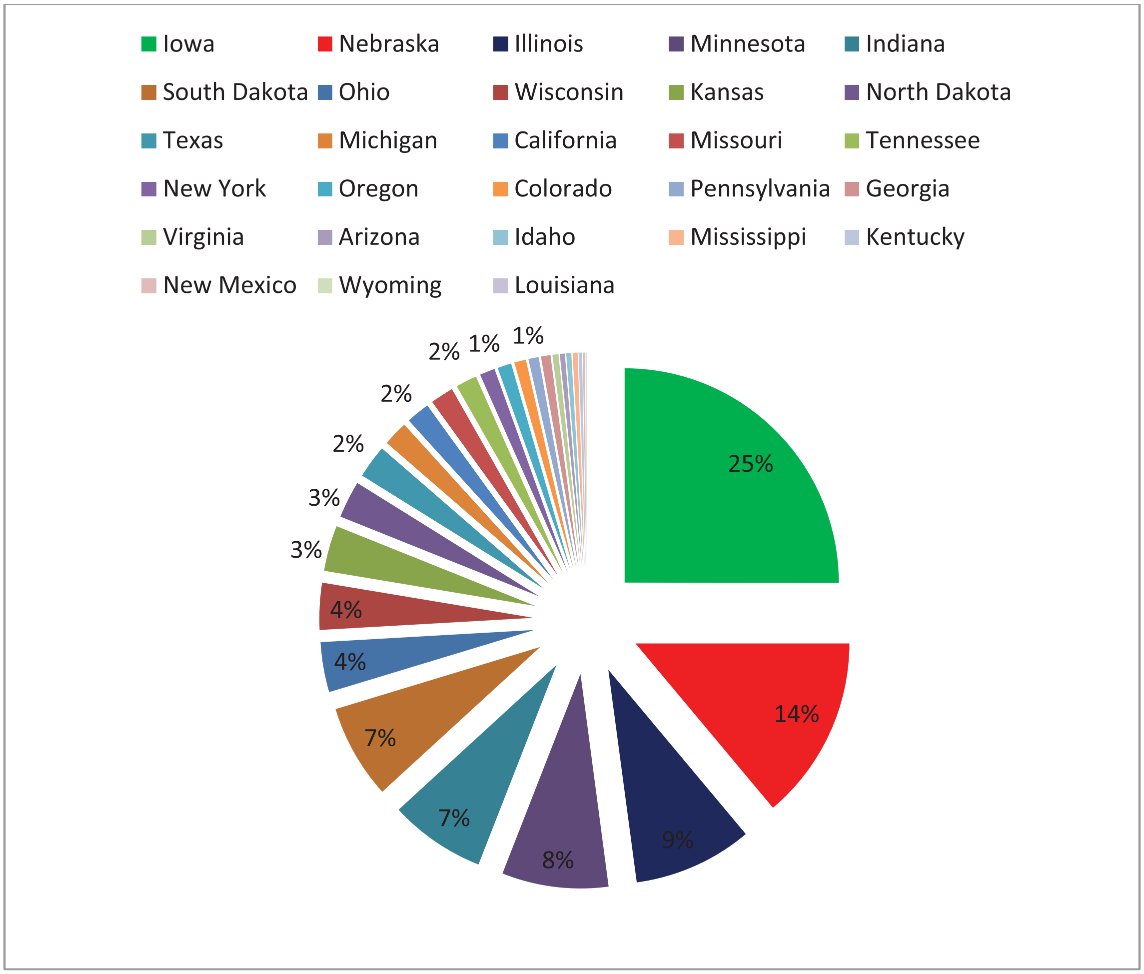


Figure 1-6 ranking the states by ethanol capacity (Source: Official Government Nebraska Website)

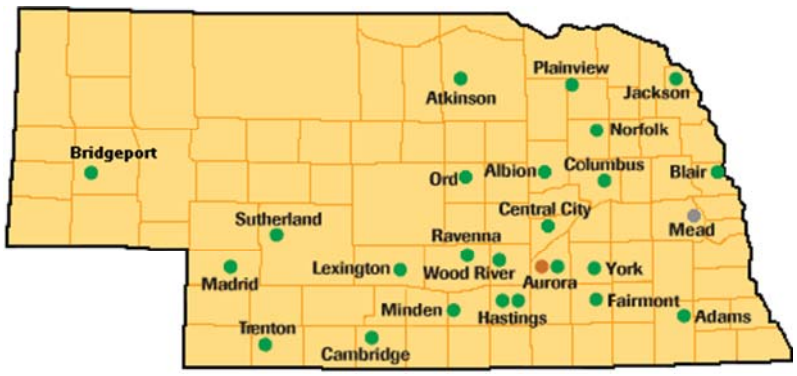


Figure 1-7 Nebraska ethanol plants

(Source: Official Nebraska government website)

Ethanol-blended market share in Nebraska has increased from 35% in 1993 to 76% in 2011. Ethanol–blended fuel's market share fell in 2001 because the ethanol price began rising faster than the gasoline price. Figure 1-8 indicates a significant increase in ethanol–blended fuel market share from 2002 to 2005. This significant increase is due to the availability of ethanol–blended fuel, the price at the pump, and strong demand for ethanol. The lower market share of ethanol- blended fuel during 2006 was the price premium of ethanol to gasoline. In 2007, market share increased with additional ethanol operating capacity pushing ethanol prices lower. In 2008, the market share continued to rise. In the fall of 2009, corn and ethanol prices decreased. But the market share was not large enough to overcome 2008's record market share.

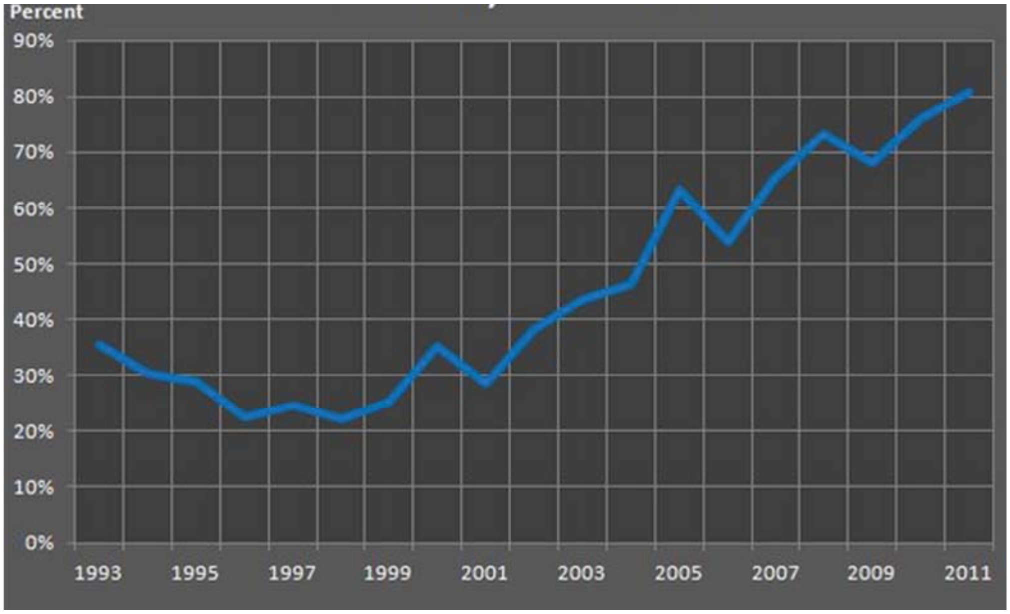


Figure 1-8 Nebraska ethanol-blended fuel share (Official Nebraska Government Website)

1.7.Methods to evaluate ethanol capital investment projects

The methods that are currently used to evaluate capital investment projects in the ethanol vary widely, and there is no standard model that is used for ethanol investment analysis.

Zou and Pederson (2008) use real option analysis to study ethanol capacity expansion. They apply discounted net present value and a binomial option pricing model in the expansion analysis. First, they consider the option to expand the scale of a conventional ethanol plant. Second, they evaluate the option to choose a production technology given three dry-milling choices – a conventional natural gas-fueled plant, a stover-fueled plant, and a stover-plus-syrup-fueled plant. They develop input-output coefficients and annual cash flow forecast for a hypothetical small ethanol plant with 50 million gallon capacity using available industry and market price data. They do scenario analysis to evaluate the effect of profitability and volatility on the expansion.

Schmit, et al (2009) analyze investment and operating decisions of corn-based dry-grind ethanol facilities using net present value (NPV) and real options methods.(Schmit, et al 2009). In this study, they used both NPV and real options frameworks to calculate entry and exit ethanol gross margin triggers. They found that if there is an expected upward trend in gross margins, investors would be willing to enter the industry sooner. If they are already in the industry, they would delay exiting it if the expected margin in positive. But the authors did not consider the changes in the demand and margin at the same time.

There are some uncertainties in ethanol production profitability. According to Tiffany and Eidman (2003), corn prices, gas prices, and ethanol prices affect the profitability of ethanol industry. In other words, ethanol price uncertainty derives from variability in the cost of feedstuffs (corn), variability in the cost of energy, and variability in the price of ethanol. Higher corn prices relative to the price of ethanol imply less operating margins and are contributing to the delayed corn ethanol plant investment (Feinman, 2007). Investors in ethanol processing need to consider the volatility of costs and prices in making any decision to invest.

Risk and uncertainty are considered by stochastic simulations in some of the studies about ethanol investment. Stochastic simulation is used to evaluate a firm’s profitability and returns using different pricing scenarios (Richardson et. al. 2007; Gallagher et. al. 2007).

Richardson et al. (2007) developed a simulation model for 50 million gallons per year ethanol plant in the Texas Panhandle based on accepted input/output coefficients and investment costs. Historical risks for costs and prices were used to incorporate stochastic values for these variables.

Richardson et al. (2007) developed a Monte Carlo simulation model of the economic activity for a bio-ethanol plant to quantify the risks that influence the bio-ethanol profitability from wheat in the winter rainfall region of South Africa. Uncertainties in this study were government policies and rates of return.

Gallagher et al. (2007) used simulations to estimate the plant scale and profitability implications of an ethanol processing firm, a joint producer/processor enterprise, and a processing co-op. In this study, economies of production size and profitability or costs changing by plant size are considered.

2. Methodology

2.1.Ethanol production costs and revenues

Unlike fixed cost in conventional manufacturing systems, ethanol plants' fixed cost is expressed per gallon, not as a capital cost. The fixed cost consists of labor costs and other costs such as operating supplies, maintenance supplies, insurance, local taxes, interest cost of borrowing money and capital depreciation. According to USDA, the fixed cost is calculated per gallon which is 19.35 cents/gal for natural gas-based plants; the detail is shown in appendix A. (U.S. Environmental Protection Agency, 2007). Figure 2-1 shows the costs.

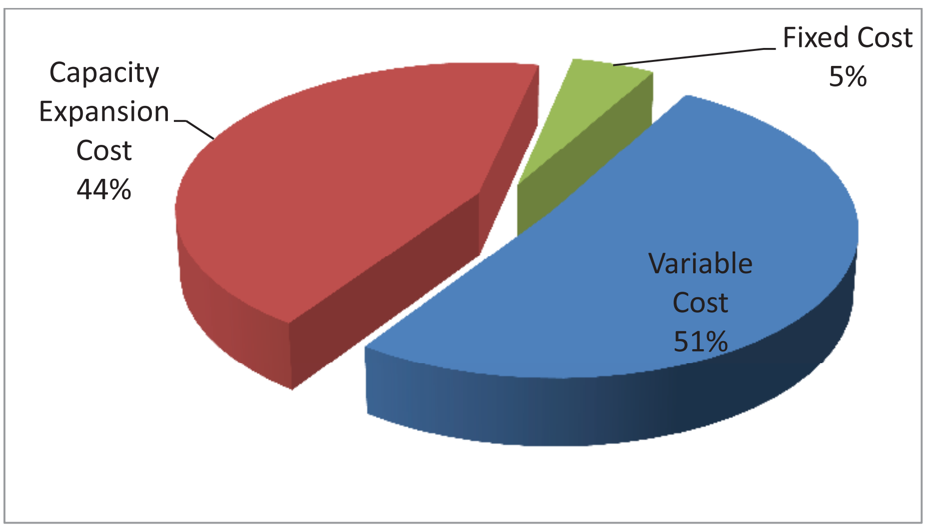


Figure 2-1 Ethanol Costs

The variable cost of production depends on some factors such as corn price, gas price, electricity price, and labor cost. The cost function that is developed by Perrin (2009) is used in this study for calculating the variable cost of production. The cost function describes per-gallon operating cost as a linear function of the prices of inputs.

$$\text{Variable Cost} = 0.57\ P_{electricity} + 0.02016P_{gas} + 0.000480P_{Labor} + 0.274P_{Corn}$$

$P_{electricity}$ is the price of electricity per kilowatt hour, P_{gas} is the price of natural gas per MMBTU; P_{Labor} is the Employment Cost Index (series CIS101) from the Bureau of Labor Statistics, P_{Corn} is the price of corn per bushel.

Figure 2-2 shows that more than 80% of the variable cost for producing ethanol is from corn.

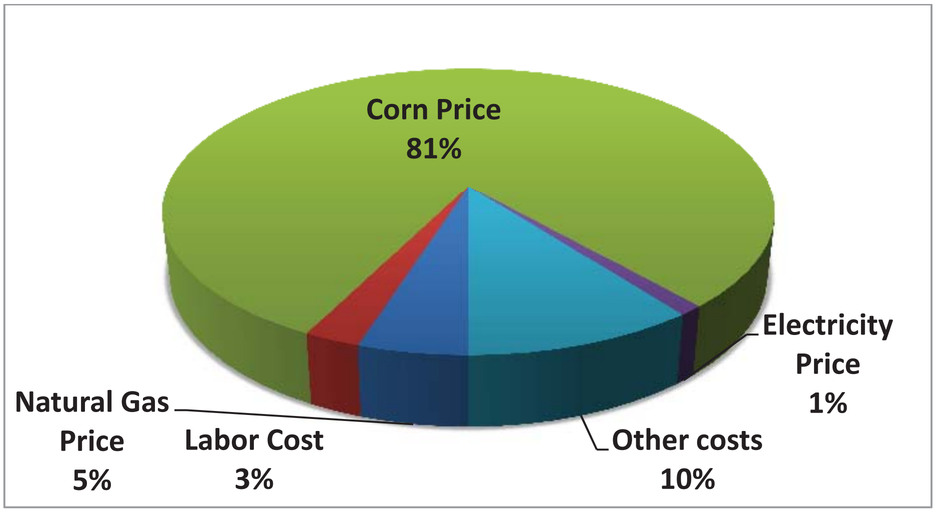


Figure 2-2 Ethanol production variable cost

The capacity expansion cost is the cost of expanding the capacity by one gallon of ethanol. Capacity expansion cost in a dry mill ethanol industry is $1.53 with a standard deviation of $0.32 per gallon. (Gallagher et al. 2005)

Ethanol accounts for 70% of the total revenue of the plants that use dry mill technology to produce ethanol. The other 30% of the revenue of the company is from the co-products, distillers dried grain with soluble (DDGS), and carbon dioxide.

2.2.Ethanol-corn margin

The ethanol-corn crush margin refers to the process of refining corn into fuel ethanol. While costs vary, corn is the main input cost, representing approximately 70 percent of the per gallon cost of creating ethanol.

The ethanol-corn crush is the difference between the price of the finished fuel ethanol, DDG, and the price of corn. Because ethanol is traded in dollars per gallon, DDG is traded in dollar per pound and corn in cents per bushel, a conversion of prices into equal units is necessary.

One bushel of corn yields 2.8 gallons of ethanol and 17 pounds of DDG. So if we want to unify the units into dollar per gallon, we can say that one gallon of ethanol and 6.071 pounds of DDG is the result of processing $1/_{2.8}$ bushel of corn. (Table 2-1)

Table 2-1 Corn crush margin

Corn	Ethanol	DDG
1 bushel	2.8 gallon	17 Pounds
1/2.8 bushel	1 gallon	6.071 pounds

So the margin equals:

(price of ethanol in dollar per gallon)+6.071*(price of DDG in dollar per pound)-1/2.8 *(price of corn in dollar per bushel). The unit of margin is dollar per gallon.

2.3. Historical data

It is better to use the data from 2007 to 2011 for prediction because the trend in data from before 2007 is affected by other factors such as start of Persian Gulf War in 1990, start of Iraq war in 2003 or recession. The fixed cost and capacity expansion costs are 19.35 cents/gal and 1.53 $/gallon, respectively. It is assumed that these costs inflate by a rate of four percent per year. Discount rate is 1/(1+0.04)=96%.Table 2-2 shows the historical data.

Table 2-2 Historical Data

Year	Gas price ($/unit)	Corn price ($/ bushel)	Electricity cost ($/kwh)	other costs ($)	labor cost ($)	variable cost ($/gal)	ethanol price ($/gal)	DDG Price ($/ Pound)	shortage cost= Lost profit ($/gal)
2001	$5	1.89	$0.04	167.9	$108.20	$0.92	1.48		$0.56
2002	$5	2.13	$0.04	167.9	$108.20	$0.96	1.12		$0.16
2003	$5	2.24	$0.04	167.9	$108.20	$1.02	1.35		$0.33
2004	$5	2.44	$0.04	167.9	$108.20	$1.09	1.69		$0.60
2005	$5	1.96	$0.04	167.9	$108.20	$1.00	1.8		$0.80
2006	$5	2.28	$0.04	167.9	$108.20	$1.08	2.58		$1.50
2007	$5	3.59	$0.04	167.9	$108.20	1.4331112	1.93	144.04	0.93412222
2008	$5	5.07	$0.04	167.9	$108.20	1.8626216	2.17	165.98	0.81121069
2009	$5	3.52	$0.04	167.9	$108.20	1.3760304	1.61	119.03	0.595285165
2010	$5	3.97	$0.04	167.9	$108.20	1.4888304	1.75	117.84	0.61887292
2011	$5	6.67	$0.04	167.9	$108.20	2.2202808	2.55	209.33	0.965140415

2.3.1 The prices

Figures 2-3, 2-4, and 2-5 show the historical weekly data for ethanol, corn, and DDG prices. The historical data for the prices are available weekly from USDA Livestock and Grain Market News and 2012 State Ethanol Plant Reports. The horizontal axis shows the date of the price which is the month and the week. It starts from Jan 1 2007 which means the first week of January 2007 and ends at Dec 5 2011 which is the fifth week of December 2011. The figures are made compact in order to fit in the page so some of the dates are not visible here. The crush margin historical data can be found by the definition of margin in Figure 2-6 in Section 2.4.

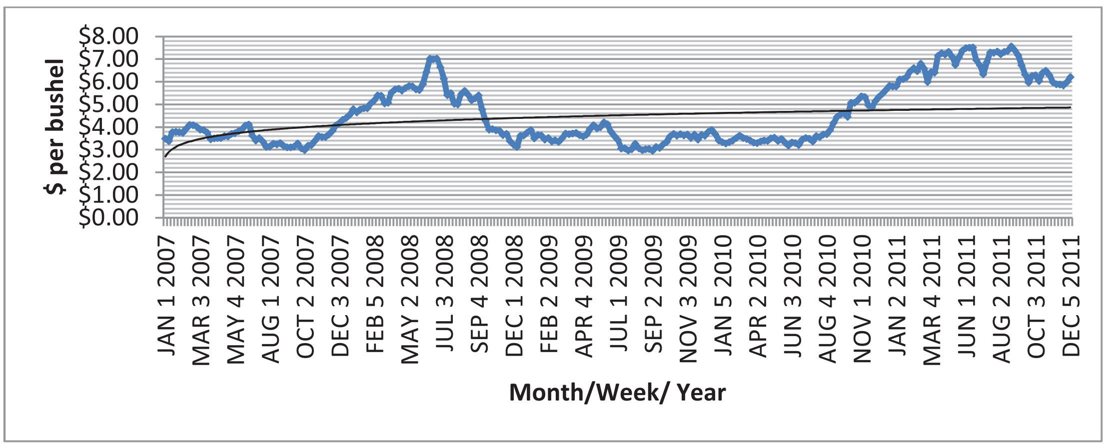


Figure 2-3 Nebraska Corn Historical weekly Prices from 2007 to 2011

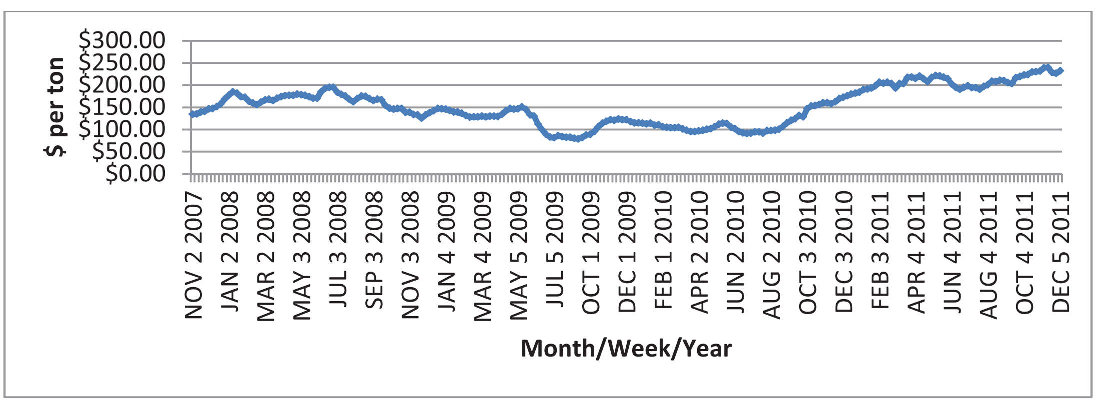


Figure 2-4 Nebraska DDG weekly Prices from 2007 to 2011

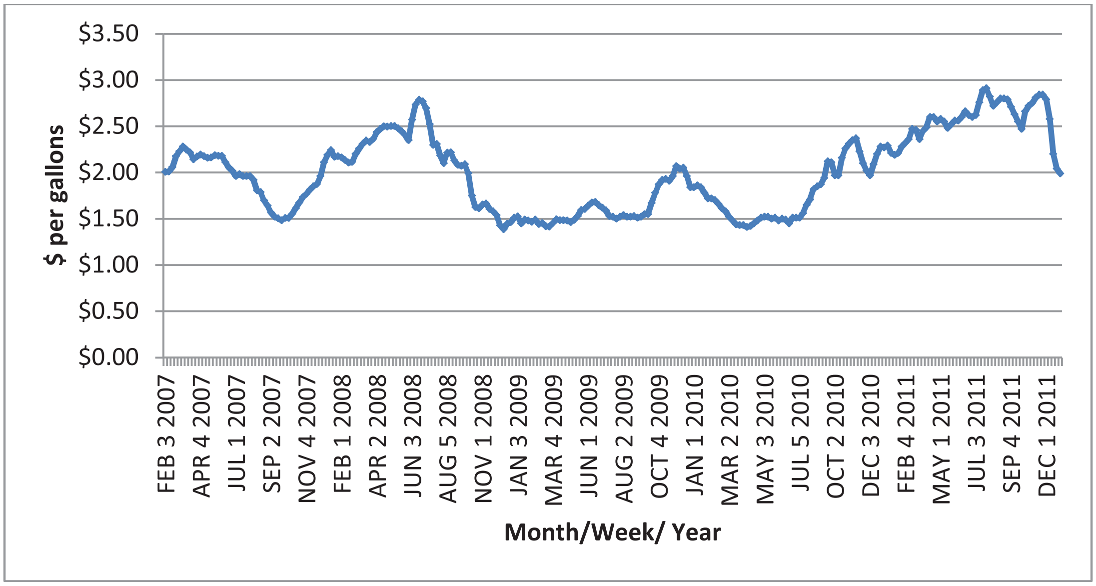


Figure 2-5 Nebraska Ethanol weekly Prices from 2007 to 2011

Figure 2-6 Historical weekly crush margin from 2007 to 2011.

2.3.2 The demand

The monthly data for national ethanol demand is available from Renewable Fuels Associations (RFA). In order to find the ethanol demand for Nebraska, we divide the monthly ethanol capacity of Nebraska by the total ethanol capacity in the U.S. in that month. The resulted numbers are the monthly Nebraska share of ethanol capacity. Then the ethanol demand for Nebraska can be found by multiplying this number by the total ethanol demand in the U.S. Nebraska production capacity data is available at the Official Nebraska Government Website Reports. Figure 2-7 indicates the monthly historical ethanol demand in U.S. and Nebraska from 2007 to 2011.

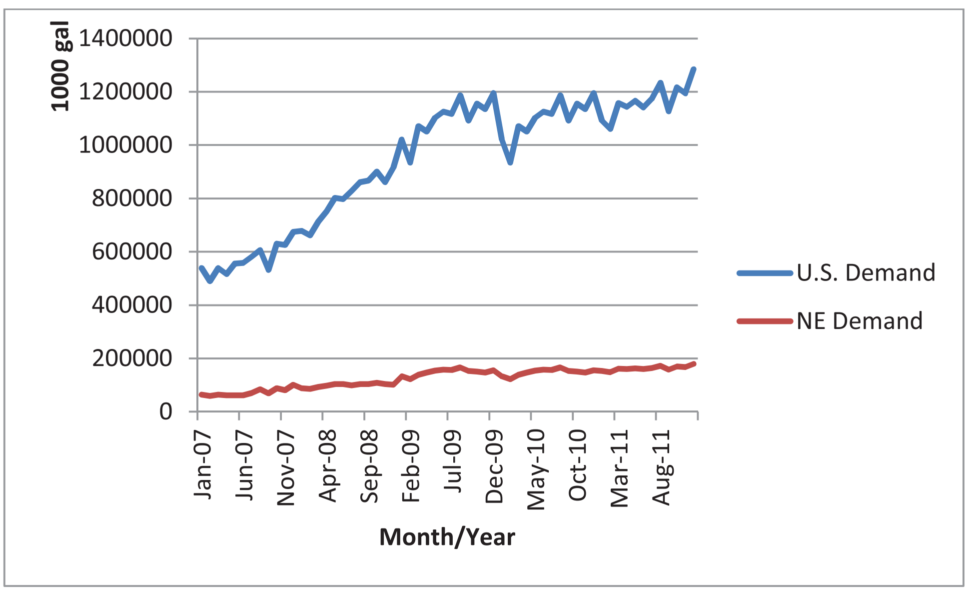


Figure 2-7 Monthly historical ethanol demand for U.S. and Nebraska

2.4.Future data prediction

2.4.1The prices

The forecast for prices is found from USDA Agricultural Long-term Forecast Report. The Report has the forecast for ethanol and corn, but not the DDG. However, DDG price is a percentage of the corn price. Figure 2-8 shows the historical DDG prices as a percentage of the price of corn from 2007 to 2011. The average percentage is 90%.

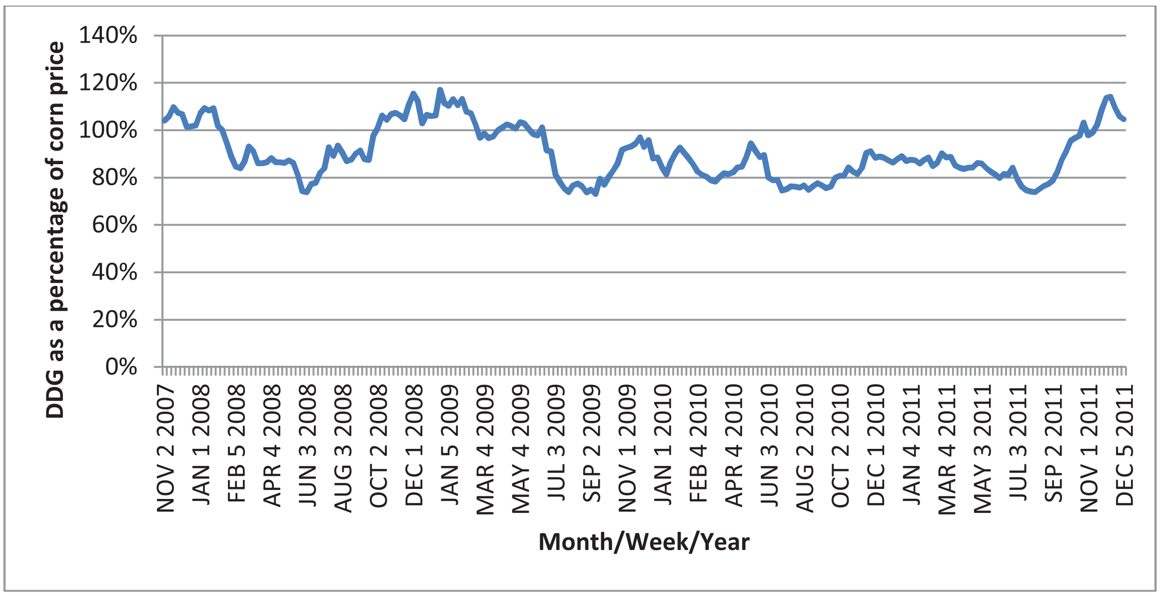


Figure 2-8 DDG price as a percentage of the corn price during last five years. from USDA Livestock and Grain Market News, State Ethanol Plant Reports

This percentage is used to forecast the price of DDG for the next five years. Because the forecast of corn price is available from USDA agricultural projection report, the price of DDG can be easily found. Table 2-3 shows the prices projection for 2012 to 2016.

Table 2-3 Future prices for ethanol, corn, and DDG (USDA Agricultural Projection Report)

	2012	2013	2014	2015	2016
Ethanol (E85) Price ($/gal)	2.976	2.558	2.662	2.758	2.789
Corn Price ($/Bushel)	5.0	4.3	4.4	4.5	4.5
DDG Price ($/ton)	177.156	152.3542	155.8973	159.4404	159.4404

2.4.2 The demand

The Nebraska ethanol demand is predicted for the next 5 years using nonlinear regression. To predict the future data, regression analysis by the Trend lines in Microsoft Excel have been used to graphically display trends in demand. By using regression analysis, it is possible to extend a trend line in a graph of real data to predict future values.

Microsoft Excel has six different trend/regression types. The type of data determines the type of trendline that should be used. When a trendline is fitted to the data, Excel automatically calculates its R-squared value. The more the R-squared is, the more reliable the trendline is. Figure 2-9 indicates the nonlinear regression for the demand for Nebraska. Figure 2-10 shows the monthly prediction. The prediction is then converted to yearly basis for 2012 to 2016 in Figure 2-11.

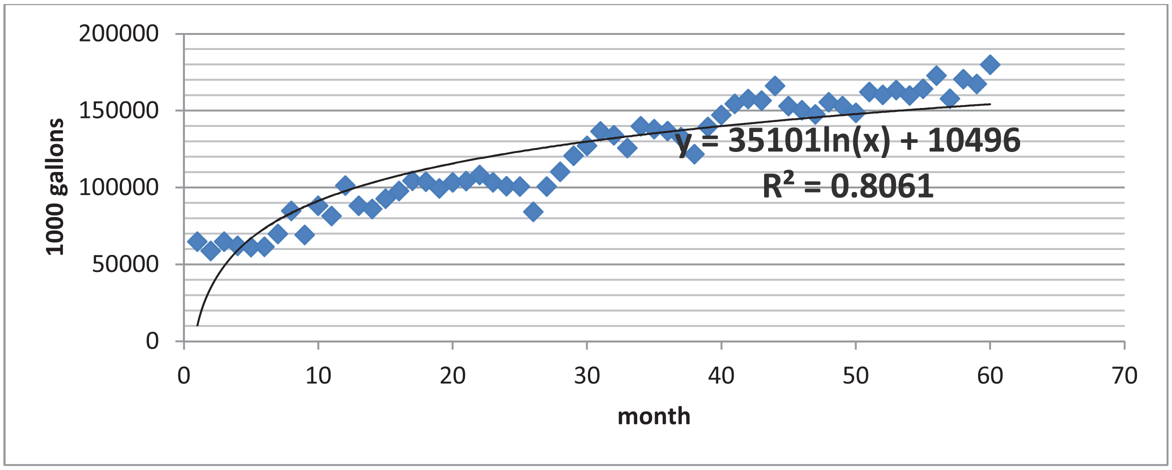


Figure 2-9 Nebraska Ethanol monthly Demand from 2007 to 2011

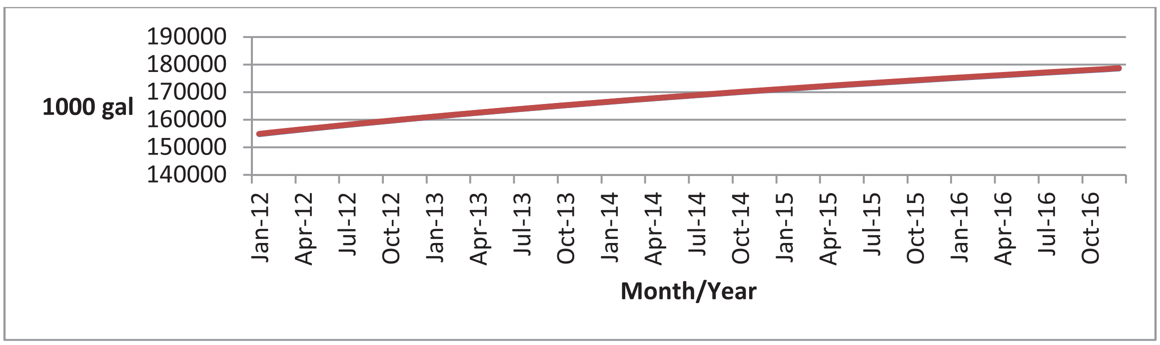


Figure 2-10 Forecasted Monthly Ethanol Demand from 2011 to 2016

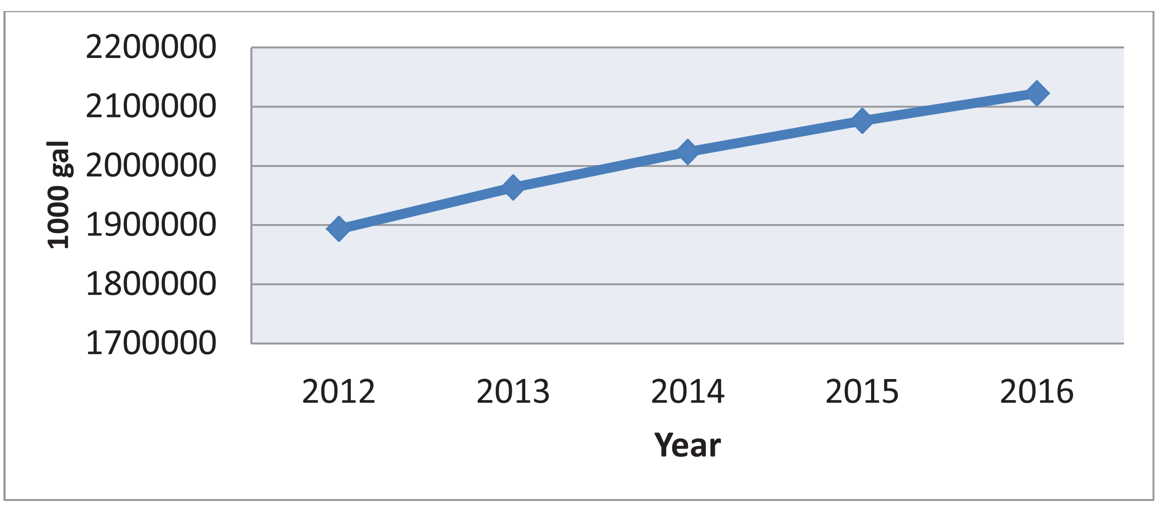


Figure 2-11 Forecasted Yearly Ethanol Demand Data

The average capacity of Nebraska from 2007 to 2011 is divided by the size of one plant to calculate the plant's share of total capacity. Considering the size of the plant is 100 million gallons per year, the average share is 7.6%. Then the predicted demand for the plant can be calculated by multiplying 7.6% by the predicted demand for Nebraska. Table 2-4 shows the predicted demand for the plant.

Table 2-4 Finding Ethanol Plant Demand from Nebraska Demand

Year	NE Demand	Plant Demand
2012	2,018,449,339	153,402,149
2013	2,123,453,237	161,382,446
2014	2,214,411,751	168,295,293
2015	2,294,642,845	174,392,856
2016	2,366,412,005	179,847,312

For example, the ethanol demand for the plant for 2012 is 7.6% of the total demand for Nebraska.

2.5.Assumptions

The project does not have a special case study but a conventional ethanol plant is considered in the project. The data of the project related to ethanol price, demand, and cost of the plant are taken from papers, the USDA reports, Renewable Fuels associations (RFA) reports, and the official Nebraska government websites. The interest rate is the average of three-month US Treasury Bills for the past 20 years. The average is 4%. (Figure 2.12)

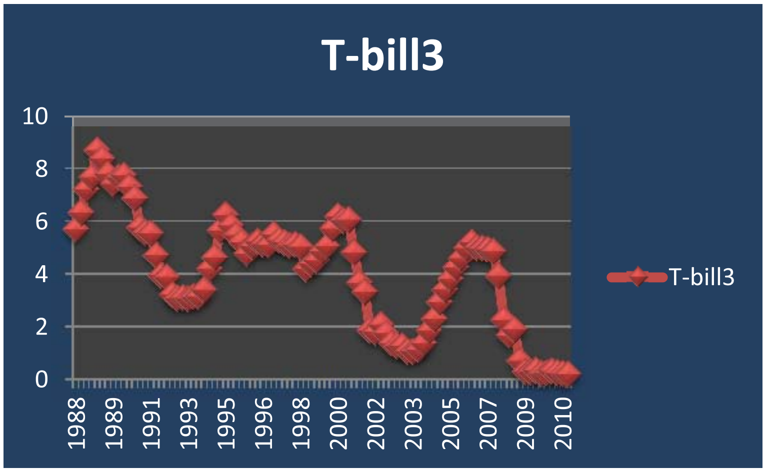


Figure 2-12 Three Months US Treasury Bills from 1988 to 2010

The other assumptions that are considered for Nebraska ethanol expansion and a medium sized plant expansion are as follows:

- ✓ Whatever is produced is consumed.
- ✓ A medium sized ethanol plant is considered in the project with initial capacity of 100 million gallons per year.
- ✓ The discount rate is found from the average of three-month US treasury bills for the past 20 years.
- ✓ Labor cost, electricity cost, natural gas price, and other cost in the variable cost part of the model are assumed constant.
- ✓ The delay to expand the capacity is one year.
- ✓ The possible capacity expansion for Nebraska is assumed to be in the range of 0 to 600 with increments of 100.

- ✓ The possible capacity expansion for a medium sized plant is assumed0, 50, and 100.

- ✓ The initial capacity for Nebraska is assumed 1958 million gallons per year.

- ✓ The ethanol production and capacity expansion costs for Nebraska are assumed the same the expansion costs in a medium sized ethanol plant.

Figure 2-13 shows the inputs and outputs of the model. The inputs of the model are the costs including the expansion cost, fixed cost, and the variable cost which includes the prices for ethanol, corn, and DDG along with the other costs such as electricity and labor. The discount rate and the ethanol demand are also inputs to the model. The results of the model are ethanol production quantity and the capacity expansion of the plant.

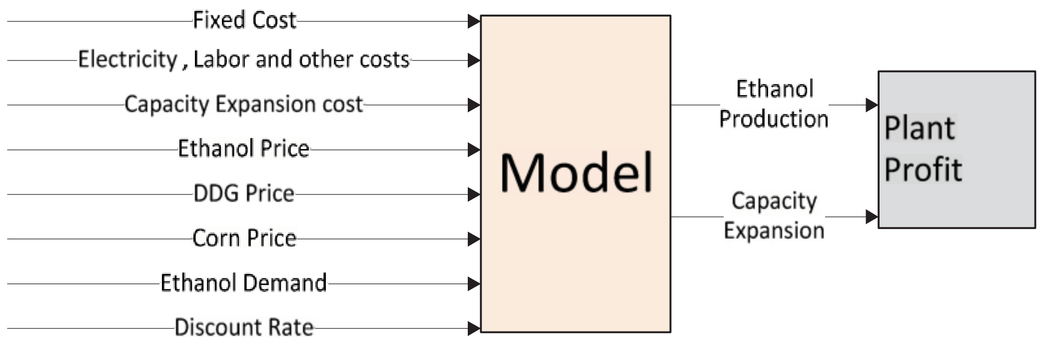


Figure 2-13 Inputs and Outputs to the Model

2.6. Mathematical Model

Each ethanol plant has a specific capacity. The capacity of the ethanol plant is defined by the gallon production of ethanol each year. For instance, the capacity of a conventional ethanol plant is 100 million gallons per year. Annual profit of a plant is defined by factors such as annual ethanol demand, ethanol price, quantity of production, and total cost including fixed, variable, and expansion costs. So the profit of the plant is a function of the factors mentioned above. In order to decide when and how much to expand, we should first develop the profit model of the plant. By developing the model of the total profit of the plant for a 5-year period, and by solving the model, the ethanol manager can best decide when to expand the capacity and how much to expand. The expansion decision unit is gallon ethanol. This model can be used for Nebraska as well. With the objective of maximizing the total ethanol profit of Nebraska plants, the optimum capacity expansion and production level decisions will be made for the Nebraska ethanol industry. Total profit function of a plant is a recursive model that can be solved by dynamic programming.

2.6.1 Model Notation

Parameters

$r(t)$: Price of ethanol at the beginning of year *t* ($ per gallon)

$D(t)$: Demand for ethanol during year *t* (gallon)

$c_f(t)$: Fixed cost of ethanol production per gallon at the beginning of year *t* (dependent on capacity) ($ per gallon)

$c_v(t)$: Variable cost of per unit ethanol production at the beginning of year *t* ($ per gallon)

L: The delay between the decision time to increase the capacity and when the capacity is usable (years)

$c_e(t)$: Capacity expansion cost at the beginning of year *t* ($ per gallon)

$S(0)$: Initial capacity of the ethanol plant (gallon) at beginning of year 2012

$\alpha(t)$: Shortage cost per unit of excess demand ($ per gallon)

β : Discount rate

T : Planning horizon (years)

Decision Variables

$S(t)$: Capacity at the beginning of year *t* (gallon)

$Pr(t)$: Production during year *t* (gallon)

$A(t)$: Possible capacity increase at the beginning of year *t* (gallon)

2.6.2 Profit Function

Revenue

The ethanol price per gallon is $r(t)$, the revenue for the plant according to its production will be

$$r(t) * min\{D(t), Pr(t)\}$$

In other words,

$$\text{Revenue} = \begin{cases} r(t) * D(t) & if \ D(t) \leq Pr(t) \\ r(t) * Pr(t) & if \ D(t) > Pr(t) \end{cases}$$

Since the demand is always greater than production (one of the assumptions) the revenue is $r(t) * Pr(t)$.

Cost of Production

Cost of production includes fixed and variable costs. The fixed and variable costs are $c_f(t)$ ($ per gallon) and $c_v(t)$ ($ per gallon) respectively. The total cost is $c_f(t)S(t) + c_v(t)\,Pr(t)$.

Cost of Energy

The energy consumed for converting corn to ethanol includes thermal and electrical energy. According to Shapouri (2002), the amount of electricity used per gallon is 1.09 Kwh and the amount of thermal energy used is over 36,000 BTU per gallon ethanol.

There is no special contract between ethanol plants and electricity utilities. The ethanol plants pay the amount of electricity they consume the same as residential users, but they pay more (14-15%) than residential electricity price since they are constant users. So we can consider the electricity price fixed in the model.

Shortage Cost

If $D(t) > \text{Pr}(t)$ then there is a demand for ethanol that cannot be met, so there will be a shortage cost or lost profit cost that can be shown as:

$$\alpha(t)(D(t) - Pr(t))$$

Where $\alpha(t)$ is the shortage cost per unit of excess demand ($ per gallon) and $D(t) - Pr(t)$ is the amount of excess demand. We can assume that excess demand is lost and in this case the problem will be simplified. However, in real problems there is a strategy of backorder which can be used to meet the excess demand.

2.6.3 Objective function and constraints

The objective is to maximize the total discounted profit of the plant during the planning horizon.

$$\max \sum_{t=1}^{T} \beta^t R(t) \qquad (1)$$

s.t:

$$Pr(t) \leq S(t) \qquad (2)$$

$$S(t-1) \leq S(t) \qquad (3)$$

$$S(t) = S(t-1) + A(t-L) \qquad (4)$$

$$S(t) \geq 0, Pr(t) \geq 0$$

Equation (1) shows the total discounted profit. Total profit of the plant is equal to:

$$R(t) = r(t) * Pr(t) - c_v(t) * Pr(t) - \alpha(t)(D(t) - Pr(t))^+ - c_f(t) * S(t) - c_e(t) * (S(t) - S(t-1))$$

Constraint (2) states that the production is always less than the capacity. Constraint (3) allows only the increase of the capacity, but not a decrease. Constraint (4) states that there is a lag between when the manager decides to increase the capacity of the plant and when the increased capacity is usable. This delay is shown by L and it is represented in years.

The decision to increase the capacity by $A(t)$ at time t has its effect L periods later at $t + L$. In other words, the capacity increase at period t is the result of the decision made L periods before at $t - L$. For $A(t)$, it is assumed that it is possible to increase the capacity by 0, 50, or 100 million gallons for a single plant and 0, 100, …, or 600 million gallons for all Nebraska plants.

2.7.Dynamic Programing Model

The problem is a 5-year capacity expansion problem. Demand in each year is random. There is no inventory in ethanol plant. In other words, the storage will occur in terminals (for blending and storage) which are out of scope of the study. Therefore, all the ethanol produced will be sold. But if the plant produces less than demand, a shortage cost ($\alpha(t)$ per gallon) is considered. If the plant cannot meet the demand on time, the demand will be lost. Based on the plant capacity, the plant manager decides on how many gallons of ethanol to produce without knowing the demand at the beginning of each year. It is assumed that the plant can produce ethanol by increments of 10 million gallons.

This problem is formulated as a deterministic capacity expansion model with following characteristics.

- ❖ Decision: deterministic
- ❖ State transition (next state): deterministic
- ❖ Revenue (cost): deterministic for each state transition

The goal is to determine an optimal production and capacity expansion policy to maximize the expected net profit during a 5-year planning horizon.

State and Decision

- State = $(t, S(t))$
    - t: stage = period (year).
    - $S(t)$: capacity at the beginning of year t.
- Decision Sequence = $(Pr(1)\,, A(1), Pr(2)\,, A(2), \ldots, Pr(5)\,, A(5))$
    - $Pr(t)$: gallons of ethanol produced during year t.
    - $A(t)$: capacity increase at time t, this capacity will be applicable at time $t + L$

Since the model is solved for a 5-year planning horizon, there is no capacity expansion decision in year 5, which means $A(5) = 0$.

In this study, L is considered one year for simplicity. In other word, if the manager decides to increase the capacity this year, it will take one year to install new equipment, recruit more personnel, and so on to expand the plant capacity by $A(t)$ gallons. So, new capacity would be $S(t) + A(t)$ gallons.

Objective Value Function

- $OVF = f_t(S(t))$: The maximum expected net profit incurred during the years $t, t + 1, \ldots, 5$ when the capacity at the beginning of year t is $S(t)$ gallons

Functional Equation

- Backward:

$$f_t\big(S(t)\big) = \max_{\Pr(t)}\{R(t) + \beta f_{t+1}\big(S(t+1)\big)\}; for\ t = 1,2,3,4$$

- $Pr(t) \leq S(t)$
- $S(0) = 100{,}000{,}000$

Production is always less than or equal to the capacity. Moreover, since there is a shortage cost in the model, it is assumed that the production level is less than the demand at each year.

- Boundary Value, $t = 5$:

$$f_t(S(t)) = \max_{\Pr(t)}\{R(t)\};$$

  - $A(t) = 0$

- Answer to the Problem: $f_1(100000000)$

2.8.Model Validation

One method to validate the model is to solve the model using the data of a real system, and then compare the result of the model to what really happened. Because we have the historical real data for ethanol production and expansion in Nebraska from Official Nebraska Government Website, the model is solved for Nebraska. Then the result of the model for Nebraska (capacity expansion and production level) is compared to the real production and expansion from 2007 to 2011 in the Nebraska ethanol industry. The absolute relative difference is calculated for each year. Table 2-5 shows the result of the model that is solved for Nebraska. The initial capacity for the model is the real

Nebraska ethanol production capacity of year 2007. According to the result, the best decision is to expand the capacity in the first, second and third year by 500, 300, and 300 million gallons, respectively, and not to expand in the last two years. Table 2-6 shows the real capacity expansions and production level in Nebraska from 2007 to 2011.

Table 2-5 Model solution for capacity expansion in Nebraska

Year	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)
2007	655,500,000	655,500,000	500,000,000
2008	1,155,500,000	1,155,500,000	300,000,000
2009	1,455,500,000	1,453,362,900	300,000,000
2010	1,755,500,000	1,755,500,000	0
2011	1,755,500,000	1,755,500,000	0

Table 2-6 Real Capacity Expansion in Nebraska

Year	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)
2007	655,500,000	655,500,000	531,200,000
2008	1,186,700,000	1,186,700,000	239,630,000
2009	1,426,330,000	1,178,670,000	305,840,000
2010	1,732,170,000	1,687,920,000	219,330,000
2011	1,951,500,000	1,926,500,000	0

Table 2-7 shows the relative difference of the result of the model and the real system. Because the initial capacity for the model in 2007 is the real capacity, the difference is zero. For 2008, 2010, and 2011, the relative difference is almost below 9%. However, for 2009, there is a 23% difference between the model result and the real production level. This difference is due to the low margin in 2009. The model shows the decision not to expand in 2009 because of the very low range of margin.

Table 2-7 Relative Differences for production and capacity

Year	Relative difference for production (%)	Relative Difference for Capacity (%)
2007	0	0
2008	2.629139631	2.629139631
2009	-23.30532719	-2.045108776
2010	-4.003744253	-1.346865492
2011	8.876200363	10.04355624
Average	7.762882288	3.212934028

The average relative difference between the model result and the real data for capacity is approximately 3% and for production level is 7.7%. These numbers are small enough to confirm the validity of the model.

3. Results and Scenario testing

3.1 Single plant results

The model is solved for predicted data for year 2012 to 2016. Table 3-1 shows the dynamic programming solution for a plant of size 100 million gallons per year.

Table 3-1 Optimum Capacity Expansion and Production Quantity for a Medium-Sized Plant

Year	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	50,000,000	139,739,412
2013	150,000,000	150,000,000	0	217,470,359
2014	150,000,000	150,000,000	0	147,342,975
2015	150,000,000	150,000,000	0	88,113,248
2016	150,000,000	150,000,000	0	39,238,241

According to the solution, the best decision is to expand the capacity of the plant by 50 million gallons in the first year and not to expand in the following four years.

3.2 Nebraska plants Results

Table 3-2 shows the dynamic programming solution for Nebraska ethanol industry with the initial size of 1958 million gallon per year in 2012. The result shows that the total expansion of 400 million gallon for the next five years; the best decision is to expand 200, 100, and 100 million gallons in 2012, 2013, and 2014 respectively, and no expansion in the last two years.

Table 3-2 Result for Nebraska ethanol expansion

Year	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)	$f(S(t))$ ($)
2012	1,958,000,000	1,958,000,000	200,000,000	13,261,378,042
2013	2,158,000,000	2,123,453,237	100,000,000	11,077,448,993
2014	2,258,000,000	2,214,411,751	100,000,000	8,949,295,512
2015	2,358,000,000	2,294,642,845	0	6,432,053,073
2016	2,358,000,000	2,358,000,000	0	3,356,353,371

3.3 Scenario Testing

By changing the inputs in Figure 2-13, we can see how the output will change. The most important inputs that are of interests are the ethanol demand and the price of ethanol, DDG, and corn.

3.3.1 One way Sensitivity Analysis:

3.3.1.1 Changing the margin:

Instead of changing the ethanol, corn, and DDG prices separately, it is better and easier to consider the changes in the margin. Margin is described in Section 2-4.

In order to change the margin, the profit function should be defined in terms of margin. Equation (5) shows the profit function of the plant defined in terms of margin. C is the variable cost excluding the corn price which has been already subtracted in the margin. By redefining the profit function, the results remain the same as expected.

$$R(t) = (Margin - C) * Pr(t) - \alpha(t)(D(t) - Pr(t))^{+} - c_f(t) * S(t) - c_e(t) * (A(t)) \quad (5)$$

In one-way sensitivity analysis, one of the factors is kept constant and the effect of changing the other factor on the results is studied. To study the effect of changing the margin on the results, the demand is considered unchanged.

Single plant

Table 3-3 summarizes the results of changing the margin. The numbers in the same row in the “margin changes” column give the same result. So they are summarized in one row. The numbers in the table show the ethanol capacity expansion in million gallons per year. The table explains that if the margin decreases by 40%, the decision is not to expand the capacity in the following five years. If the margin decreases by 10%, 20%, or even by 30%, the decision is to expand the capacity by 50 million gallons in the first year. This decision is the same when the margin increases by 10%. However, if the margin increases by 20%, 30%, or 40%, the expansion of 100 million gallons in the first year is the best decision.

Table3-3 One way sensitivity analysis for margin in a plant

Margin changes	2012	2013	2014	2015	2016
-40%	0	0	0	0	0
-30%, -20%, -10%, 0%, 10%	50	0	0	0	0
20%, 30%, 40%	100	0	0	0	0

Ranges may be defined to better analyze the results. Table 3-4 shows these ranges. For example, for decrease of 20% or less the range is called Vey Low. For a decrease up to 20%, the range is called Medium Low. Then there is the Base Case. The increase up to 20% is called Medium High and over 20% increase is named Very High.

Table 3-4 Defining Ranges

Very Low (VL)	>-20%
Medium Low (ML)	0 to -20%
No Change/Base Case (BC)	0
Medium High (MH)	0 to 20%
Very High (VH)	>20%

It is indicated that for a VL range of margin it is better not to expand. For a 30% decrease, the results show that we should expand by 50 million gallons in the first year but in order to range the changes and with a conservative analysis we say not to expand for VL range of margin. For ML range of margin (when it decreases by 20% or less), for BC (0%) and for MH range of margin, the decision is to expand by 50 million gallons in the first year.[5] For VH range, it would be better to at least[6] expand by 100 million gallons in the first year.

Nebraska plants

Table 3-5 summarizes the results for changing the margin. The numbers in the same row in the "margin changes" column give the same result for the specific margin change, so they are summarized in one row. The numbers in the table show the ethanol capacity expansion in million gallons per year. The table explains that if the margin decreases or increases by any percentages, the decision does not change, and it is still optimal to expand the capacity by 200, 100, and 100 million gallons in 2012, 2013, and 2014, respectively, and not to expand in 2015 and 2016. Because the most important

[5] Again in this case according to the model result we should expand by 100 mil gal when the margin increases by 20%; however, in order to analyze the scenarios by ranges we include the 20% in the medium high level and with a conservative action we decide to expand by 50.
[6] With higher increase than 40% the expansion may be higher.

factor that affects the expansion is the demand. When the demand is unchanged and we can meet the demand with the current capacity and there is no need to expand the capacity. However, for different margins, the profit is different as it is indicated in the last column of the table.

Table 3-5 One way sensitivity analysis for margin in Nebraska

Margin changes	2012	2013	2014	2015	2016	Total profit
-40%	200	100	100	0	0	$ 5,271,233,605
-30%	200	100	100	0	0	$ 7,268,769,714
-20%	200	100	100	0	0	$ 9,266,305,824
-10%	200	100	100	0	0	$ 11,263,841,933
0%	200	100	100	0	0	$ 13,261,378,042
10%	200	100	100	0	0	$ 15,258,914,151
20%	200	100	100	0	0	$ 17,256,450,261
30%	200	100	100	0	0	$ 19,253,986,370
40%	200	100	100	0	0	$ 21,251,522,479

In order to explain the result by the ranges that were defined, it can be said that for all ranges of margin (VL,ML, BC, MH, VH) the decision is to expand 200, 100, and 100 million gallons in the first three years if the demand remains unchanged.

3.3.1.2 Changing the demand

Another scenario is changing the ethanol demand. The demand of ethanol is a function of ethanol consumption and the amount of ethanol that is exported to other states. If either of these two increases in the future, the demand for ethanol will increase, and if it decreases, the demand will decrease. The ethanol demand has a direct impact in ethanol plant profitability, so we should consider scenarios of different demand for ethanol in the future. Table 3-6 summarizes the different results for different demands. The column of “demand changes” shows the different percentages of increase or decrease for demand. The changes that results in the same expansions are categorized in the same row. For instance, either10%, 20%, or 30% increases resulted in the same expansion of 100 million gallon in the first year.

Single Plant

Table 3-6 one-way sensitivity analysis for capacity expansion of ethanol for different demands in a plant

demand changes	2012	2013	2014	2015	2016
-40% , -30%	0	0	0	0	0
-20%, -10%, 0%	50	0	0	0	0
10%, 20%, 30%	100	0	0	0	0
40%	100	50	0	0	0

Table 3-6 shows that if the demand decreases by 30% or 40%, the decision is not to expand the capacity of the plant. It can be inferred from the table that if the demand decreases by 10% or 20%, the result does not change; the decision is still to expand the capacity by 50 million gallon, which is the decision for the base case. However, if the demand increases by 10%, 20%, or 30%, it would be better to expand by 100 million gallon. For VH range of demand, 40% increase, an expansion in the second year is recommended too.

In order to explain the results in terms of ranges it can be inferred that for Very Low (VL) range of demand, no expansion;, for Medium Low (ML) and Base Case (BC), 50 million gallons of expansion in the first year; and for the Medium High (MH) range, 100 million gallons of expansion in the first year is recommended. For Vey High (VH) demand, the best decision is the same as the ML range however with the 40% increase in demand an expansion of 50 million gallons in the second year is also recommended. But to be conservative the decision is to expand only 100 million gallons in the first year for VH range of demand.

Nebraska Plants

Table 3-7 shows that if the demand decreases by 20%, 30%, or 40% the decision is not to expand the capacity of ethanol in Nebraska. It can be inferred from the table that if the demand decreases by 10%, the decision is to expand the capacity in the second and fourth year by 100 million gallons. If the demand increases by 20%, the expansion in the first year should be 200 more and another expansion in the fourth year is recommended. For 30% increase in demand, the best expansion is 600, 400, and 100 in the first three years, and for 40% the expansion in the second year increases by 200.

According to the definition for ranges, for VL and ML ranges of demand, no expansion, for BC range of demand, 200, 100 and 100 million gallons of expansion in the first three years, for the MH range, 400, 100 and 100 million gallons of expansion in the first three years and for VH range of demand 600, 400 and 100 million gallons of expansion in the first three years is recommended. There are overlaps in results of some ranges for instance 30% and 40% increase in demand have different results but for But to be conservative the decision is to expand according to the lower range.

Table 3-7 One way sensitivity analysis for demand in Nebraska

Demand changes	2012	2013	2014	2015	2016
-40%, …, -20%	0	0	0	0	0
-10%	0	100	0	100	0
0%	200	100	100	0	0
10%	400	100	100	0	0
20%	600	100	100	100	0
30%	600	400	100	0	0
40%	600	600	100	0	0

3.3.2 Two- way Sensitivity Analysis:

Changes in Ethanol demand and price margins at the same time

In two-way sensitivity analysis, changing the demand and margin at the same time is studied. The demand and the margin change simultaneously in this section.

Single Plant

Table 3-8 shows the different results for different margin and demand. In the table, the changes that have the same result are categorized in the same row. For example, when the demand decreases by 10% and the margin decreases by 40% the decisions are not to expand at all, but for all other changes in the margin for 10% decrease of demand, the result shows an expansion of 50 million gallons in the first year. If demand decreases 40%, no matter what the change in the margin is, the decision is not to expand for the following years. If the demand decreases 30% and margin increases 30% or 40%, the decision is to expand the capacity in the first year by 50 million gallon. Otherwise, there will be no capacity expansion. For 20% decrease in demand, the decision is not to expand for any more than 10% decrease in margin; otherwise, it is recommended to expand the capacity by 50 million gallon in the first year. If the demand decreases 10%, the capacity will not change only if the margin decreases 40% or more. It means that for margin decrease up to 30% or increase up to 40%, the decision will be to expand in the first year by 50 million gallon. If the demand does not change, it is the case of the one side sensitivity analysis. So the result is to expand the capacity by 50 million gallon if the margin does not decrease more than 30% and does not increase more than 10% and expand by 100 million gallon if the margin does not increase more than 40% or decrease more than 20%. If the demand increases 10%, even if the margin decreases by 30% or 40%, there will be an expansion in the first year by 50 million gallon and if the margin does not decrease more than 30% there will be an expansion by 100 million gallon. We can see that the demand has a much stronger effect on the decision. The effect of demand change when it increases by 30% or 40% outweighs the effect of decrease in the margin even if it decreases by 30%.

Table 3-8 Two-way sensitivity analysis for capacity expansion of ethanol in a plant

Demand	Margin	2012	2013	2014	2015	2016
-40%	-40%,…, 40%	0	0	0	0	0
-30%	-40%,…, 20%	0	0	0	0	0
-30%	30%	50	0	0	0	0
-30%	40%	50	0	0	0	0
-20%	-40%, -30%, -20%	0	0	0	0	0
-20%	-10%,…,40%	50	0	0	0	0
-10%	-40%	0	0	0	0	0
-10%	-30%, …, 40%	50	0	0	0	0
0%	-40%	0	0	0	0	0
0%	-30%, …, 10%	50	0	0	0	0
0%	20%, 30%, 40%	100	0	0	0	0
10%	-40%	0	0	0	0	0
10%	-30%	50	0	0	0	0
10%	-20%, …, 40%	100	0	0	0	0
20%	-40%	0	0	0	0	0
20%	-30%, …, 40%	100	0	0	0	0
30%	-40%	0	0	0	0	0
30%	-30%, … ,10%	100	0	0	0	0
30%	20%, 30%, 40%	100	50	0	0	0
40%	-40%	0	0	0	0	0
40%	-30%, -20%	100	0	0	0	0
40%	-10%,0, …, 40%	100	50	0	0	0

Table 3-9 shows the results of the expansion according to the range definitions. When the demand is too low, for example, it decreases by 40% or more, the decision is not to expand when the margin is in ML range. Only if the margin increases by 30% or more, we will have an expansion in the case of VL range of demand for ethanol (30% decrease or more).

Table 3-9 Results for Different Ranges of ethanol Demand and Margin in a plant

Margin / Demand	VL	ML	BC	MH	VH
VL	0	0	0	0	50,0,0,0,0
ML	0	50,0,0,0,0	50,0,0,0,0	50,0,0,0,0	50,0,0,0,0
BC	0	50,0,0,0,0	50,0,0,0,0	50,0,0,0,0	100,0,0,0,0
MH	50,0,0,0,0	100,0,0,0,0	100,0,0,0,0	100,0,0,0,0	100,0,0,0,0
VH	0	100,0,0,0,0	100,0,0,0,0	100,50,0,0,0	100,50,0,0,0

Figure 3-1 shows the percentage of changes in the margin and demand in two dimensions and the total discounted profit of the plant in the third dimension. The figure indicates that when the margin and the demand increase by 20% and 40%, respectively, the plant will have its maximum total profit. When the demand increases by 40% and the margin decreases by 30%, the plant has the minimum profit (see appendix D for more detail). This is because of the shortage cost or lost profit in the model. The demand increases significantly but the plant cannot meet the demand, so its profit is low. Appendix B shows the different production level and capacity of a plant for different changes in the margin and demand in detail.

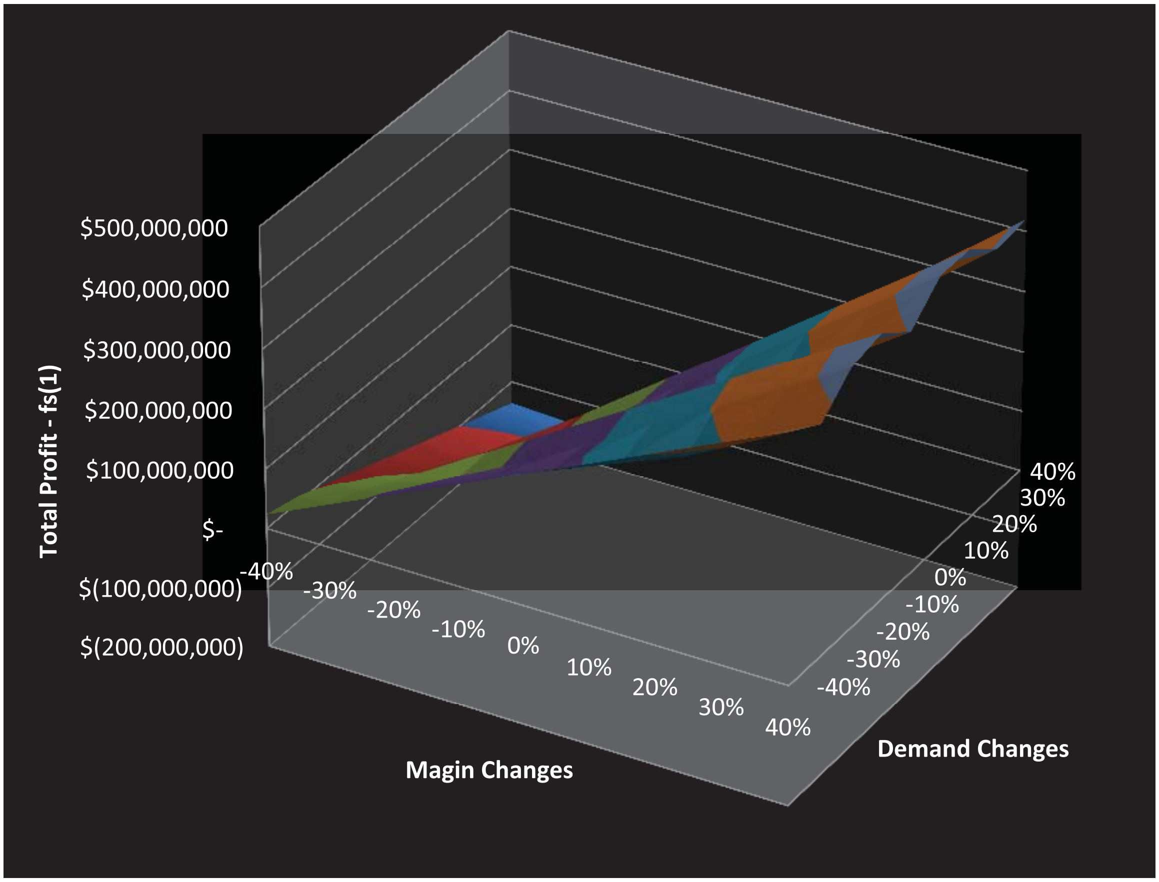


Figure 3-1 Two-way sensitivity analysis for total profit of ethanol production in a plant

Nebraska Plants

Table 3-10 shows the two-way sensitivity analysis for Nebraska ethanol expansion. Again to summarize the table the changes that have the same result are categorized in the same row. For example, when the demand decreases by 40% or increases by 40%, the result is the same, so they are presented in one cell.

Table 3-10 Two-way sensitivity analysis for capacity expansion in Neraska

Demand	Margin	2012	2013	2014	2015	2016
-40%	-40%, …, 40%	0	0	0	0	0
-30%	-40%, …, 40%	0	0	0	0	0
-20%	-40%, …, 40%	0	0	0	0	0
-10%	-40%, -30%, -20%	0	100	0	0	0
-10%	-10%, 0%	0	100	0	100	0
-10%	10%, …, 40%	0	100	100	0	0
0%	-40%, …, 40%	200	100	100	0	0
10%	-40%, …, 20%	400	100	100	0	0
10%	30%, 40%	400	100	100	100	0
20%	-40%, -30%	600	100	100	0	0
20%	-20%, …, 30%	600	100	100	100	0
20%	40%	600	100	100	100	0
30%	-40%	600	400	0	0	0
30%	-30%, …, 40%	600	400	100	0	0
40%	-40%, …, 0%	600	600	100	0	0
40%	10%, …,40%	600	600	100	100	0

Table 3-11 Results for Different Ranges of ethanol Demand and Margin in Nebraska

Margin / Demand	VL	ML	BC	MH	VH
VL	0,0,0,0,0	0,0,0,0,0	0,0,0,0,0	0,0,0,0,0	0,0,0,0,0
ML	0,0,0,0,0	0,0,0,0,0	0,0,0,0,0	0,0,0,0,0	0,0,0,0,0
BC	200,100,100,0,0	200,100,100,0,0	200,100,100,0,0	200,100,100,0,0	200,100,100,0,0
MH	400,100,100,0,0	400,100,100,0,0	400,100,100,0,0	400,100,100,0,0	400,100,100,100,0
VH	600,400,0,0,0	600,400,100,0,0	600,400,100,0,0	600,400,100,0,0	600,400,100,0,0

Table 3-11 shows different results for different ranges of the demand and the margin changes. For example, for ML for the demand and any ranges of the margin, the decision is not to expand. For MH for the demand and any ranges except the VH for the margin the decision is to expand 400, 100, 100, 0, 0 million gallons in the next five years, respectively. However, for VH range of the margin another expansion of 100 million gallon in addition to the other 600 million gallons is recommended.

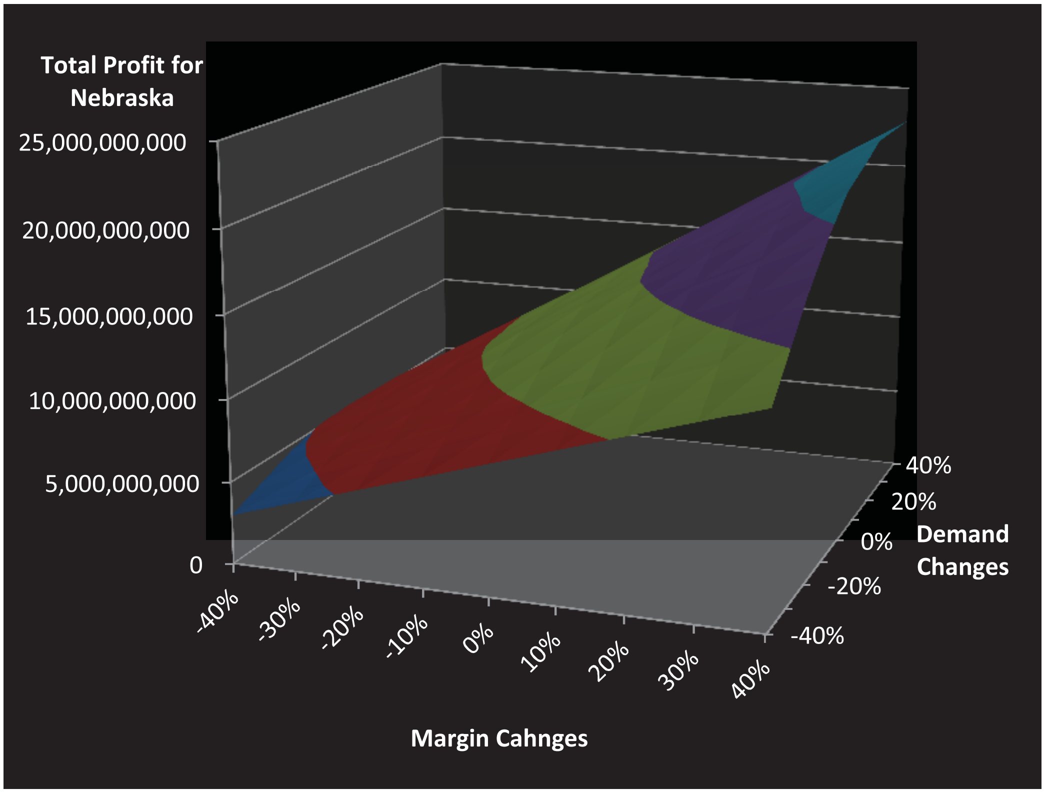


Figure 3-2 Two way sensitivity analysis for total profit of ethanol production in Nebraska

Figure 3-2 shows a three dimensional analysis of demand changes, margin changes, and the total profit of ethanol in Nebraska. The complete information of the profit for different changes of demand and margin is in Appendix E. It shows that for 20% increase in the demand and 40% increase in the margin, the ethanol in Nebraska has the highest profit. For 40% decrease in the demand and the margin, the total profit of Nebraska is minimized.

4. Conclusion

Ethanol is a renewable fuel. Whether used in low-level blends, such as E10 (10% ethanol, 90% gasoline), or in E85 (a gasoline-ethanol blend containing 51% to 83% ethanol, depending on geography and season), ethanol helps reduce imported oil and greenhouse gas emissions. In this thesis, capacity expansion and production quantity decision of ethanol in Nebraska and also for an average sized plant in Nebraska are studied. In order to the optimal expansion decision, a dynamic programming model is developed. The data used in this study such as corn, DDG, and ethanol prices, ethanol demand, natural gas, and electricity prices are all gathered from Nebraska Energy Office website, USDA reports, and renewable fuel associations statistics. The data used are from 2007 to 2011. The predicted data of demand for years 2012 to 2016 are found using a nonlinear regression and the forecasted data for the prices are all from the USDA agricultural projections long term report. The model is solved with the predicted data. The result shows that the best decision for a medium sized plant is to expand the capacity in the first year by 50 million gallon, and the best decision for Nebraska is to expand by 200, 100, and 100 million gallons in the first three years. Scenarios have been tested for changes in the margin and demand. The scenarios include the increments of 10% increase or decrease up to 40%. The results show that the demand has a stronger effect on the decision than margin. In the case of VL and VH range of demand, the margin has little impact on the expansion decision.

For future research, we plan to relax some of the assumptions made in the model to better represent real investment options. We also plan to improve our model to more accurately show the risk and uncertainty in the ethanol production. For example, the model may be expanded to include additional sources of uncertainty like energy prices and by-product sales.

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Appendix

Appendix A: Fixed cost

Cost details for 81 MMgal/yr corn ethanol plant based on USDA model.

	Natural Gas cents/gal	Coal cents/gal
MATERIAL INPUTS		
Corn Feedstock	87.19	87.19
Caustic	0.46	0.46
Alpha-Amylase	1.19	1.19
Gluco-Amylase	1.73	1.73
Gasoline	10.67	10.67
Sulfuric Acid	0.17	0.17
Lime	0.08	0.08
Makeup Water	0.06	0.06
Urea	0.33	0.33
Yeast	0.37	0.37
Corn Feed Hauling	7.67	7.67
Water	0.69	0.69
Electricity	3.50	4.02
Natural Gas	19.38	0.00
Coal	0.00	6.91
Subtotal	**133.47**	**121.53**
CO-PRODUCTS		
DDGS	-26.67	-26.67
Carbon Dioxide	0.00	0.00
Subtotal	**-26.67**	**-26.67**
TOTAL VARIABLE COSTS	***106.80***	***94.86***
LABOR		
Plant Operators' Salaries	1.31	1.56
Maintenance Salaries	1.18	1.72
Supervision & Administration	1.00	1.31
Employee Benefits	1.04	1.37
Subtotal	**4.53**	**5.96**
OTHER COSTS		
Operating Supplies	0.89	1.29
Maintenance Supplies	1.18	1.72
Insurance & Local Taxes	0.94	1.37
Captial Depreciation	11.81	17.16
Subtotal	**14.82**	**21.53**
TOTAL FIXED COSTS	***19.35***	***27.49***
TOTAL PRODUCTION COST	***126.14***	***122.35***

Appendix B: Scenario Testing Results

Appendix B shows the changes in the production and capacity level (gal) and the capacity expansion (gal) for different changes in the margin and demand.

Demand Changes: -20%

Margin Changes: -20%				
Year (t)	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	0	57,743,074
2013	100,000,000	100,000,000	0	34,148,392
2014	100,000,000	100,000,000	0	17,304,128
2015	100,000,000	100,000,000	0	6,290,701
2016	100,000,000	100,000,000	0	677,327

Margin Changes: -10%				
Year (t)	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	50,000,000	117,432,454
2013	150,000,000	129,105,957	0	177,693,336
2014	150,000,000	134,636,234	0	129,181,244
2015	150,000,000	139,514,285	0	82,545,763
2016	150,000,000	143,877,850	0	39,177,633

Margin Changes: 0%				
Year (t)	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	50,000,000	180,259,732
2013	150,000,000	129,105,957	0	233,232,375
2014	150,000,000	134,636,234	0	171,342,401
2015	150,000,000	139,514,285	0	110,895,836
2016	150,000,000	143,877,850	0	53,440,460

Margin Changes: +10%				
Year (t)	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	50,000,000	243,087,011
2013	150,000,000	129,105,957	0	288,771,414
2014	150,000,000	134,636,234	0	213,503,557
2015	150,000,000	139,514,285	0	139,245,908
2016	150,000,000	143,877,850	0	67,703,287

Margin Changes: +20%				
Year (t)	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	50,000,000	305,914,290
2013	150,000,000	129,105,957	0	344,310,452
2014	150,000,000	134,636,234	0	255,664,713
2015	150,000,000	139,514,285	0	167,595,981
2016	150,000,000	143,877,850	0	81,966,114

Demand Changes: -10%

Margin Changes: -20%				
Year (t)	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	50,000,000	59,759,195
2013	150,000,000	145,244,201	0	136,812,787
2014	150,000,000	150,000,000	0	93,258,167
2015	150,000,000	150,000,000	0	53,562,793
2016	150,000,000	150,000,000	0	22,616,617

Margin Changes: -10%				
Year (t)	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	50,000,000	123,783,652
2013	150,000,000	145,244,201	0	195,542,517
2014	150,000,000	150,000,000	0	136,787,711
2015	150,000,000	150,000,000	0	81,736,237
2016	150,000,000	150,000,000	0	36,310,387

Margin Changes: 0%				
Year (t)	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	50,000,000	187,808,110
2013	150,000,000	145,244,201	0	254,272,247
2014	150,000,000	150,000,000	0	180,317,256
2015	150,000,000	150,000,000	0	109,909,680
2016	150,000,000	150,000,000	0	50,004,156

Margin Changes: +10%				
Year (t)	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	50,000,000	251,832,568
2013	150,000,000	145,244,201	0	313,001,977
2014	150,000,000	150,000,000	0	223,846,800
2015	150,000,000	150,000,000	0	138,083,123
2016	150,000,000	150,000,000	0	63,697,926

Margin Changes: +20%				
Year (t)	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	50,000,000	315,857,026
2013	150,000,000	145,244,201	0	371,731,706
2014	150,000,000	150,000,000	0	267,376,344
2015	150,000,000	150,000,000	0	166,256,567
2016	150,000,000	150,000,000	0	77,391,696

Demand Changes: 0%

Margin Changes: -20%				
Year (t)	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	50,000,000	26,657,711
2013	150,000,000	150,000,000	0	111,685,554
2014	150,000,000	150,000,000	0	70,824,175
2015	150,000,000	150,000,000	0	38,853,879
2016	150,000,000	150,000,000	0	15,416,409

Margin Changes: -10%				
Year (t)	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	50,000,000	83,198,562
2013	150,000,000	150,000,000	0	164,577,957
2014	150,000,000	150,000,000	0	109,083,575
2015	150,000,000	150,000,000	0	63,483,564
2016	150,000,000	150,000,000	0	27,327,325

Margin Changes: 0%				
Year (t)	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	50,000,000	139,739,412
2013	150,000,000	150,000,000	0	217,470,359
2014	150,000,000	150,000,000	0	147,342,975
2015	150,000,000	150,000,000	0	88,113,248
2016	150,000,000	150,000,000	0	39,238,241

Margin Changes: +10%				
Year (t)	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	50,000,000	196,280,262
2013	150,000,000	150,000,000	0	270,362,762
2014	150,000,000	150,000,000	0	185,602,375
2015	150,000,000	150,000,000	0	112,742,932
2016	150,000,000	150,000,000	0	51,149,157

Margin Changes: +20%				
Year (t)	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	100,000,000	258,483,405
2013	200,000,000	161,382,446	0	420,413,268
2014	200,000,000	168,295,293	0	311,876,571
2015	200,000,000	174,392,856	0	204,205,341
2016	200,000,000	179,847,312	0	99,733,737

Demand Changes: +10%

Margin Changes: -20%				
Year (t)	Capacity $(S(t))$ (gal)	Production level $(Pr(t))$ (gal)	Capacity Expansion for Next Year $(A(t))$ (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	100,000,000	-11,134,237
2013	200,000,000	177,520,691	0	172,949,557
2014	200,000,000	185,124,822	0	123,504,781
2015	200,000,000	191,832,142	0	77,163,892
2016	200,000,000	197,832,043	0	35,619,810

Margin Changes: -10%				
Year (t)	Capacity $(S(t))$ (gal)	Production level $(Pr(t))$ (gal)	Capacity Expansion for Next Year $(A(t))$ (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	100,000,000	66,106,758
2013	200,000,000	177,520,691	0	249,315,736
2014	200,000,000	185,124,822	0	181,476,371
2015	200,000,000	191,832,142	0	116,145,242
2016	200,000,000	197,832,043	0	55,231,197

Margin Changes: 0%				
Year (t)	Capacity $(S(t))$ (gal)	Production level $(Pr(t))$ (gal)	Capacity Expansion for Next Year $(A(t))$ (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	100,000,000	143,347,754
2013	200,000,000	177,520,691	0	325,681,914
2014	200,000,000	185,124,822	0	239,447,961
2015	200,000,000	191,832,142	0	155,126,592
2016	200,000,000	197,832,043	0	74,842,585

Margin Changes: +10%				
Year (t)	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	100,000,000	220,588,750
2013	200,000,000	177,520,691	0	402,048,092
2014	200,000,000	185,124,822	0	297,419,551
2015	200,000,000	191,832,142	0	194,107,942
2016	200,000,000	197,832,043	0	94,453,972

Margin Changes: +20%				
Year (t)	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	100,000,000	297,829,746
2013	200,000,000	177,520,691	0	478,414,271
2014	200,000,000	185,124,822	0	355,391,141
2015	200,000,000	191,832,142	0	233,089,291
2016	200,000,000	197,832,043	0	114,065,359

Demand Changes: +20%

Margin Changes: -20%				
Year (t)	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	100,000,000	-10,971,562
2013	200,000,000	193,658,935	0	182,417,049
2014	200,000,000	200,000,000	0	124,344,223
2015	200,000,000	200,000,000	0	71,417,058
2016	200,000,000	200,000,000	0	30,155,490

Margin Changes: -10%				
Year (t)	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	100,000,000	66,264,149
2013	200,000,000	193,658,935	0	260,723,356
2014	200,000,000	200,000,000	0	182,383,615
2015	200,000,000	200,000,000	0	108,981,649
2016	200,000,000	200,000,000	0	48,413,849

Margin Changes: 0%				
Year (t)	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	100,000,000	143,499,859
2013	200,000,000	193,658,935	0	339,029,662
2014	200,000,000	200,000,000	0	240,423,008
2015	200,000,000	200,000,000	0	146,546,240
2016	200,000,000	200,000,000	0	66,672,209

Margin Changes: +10%				
Year (t)	Capacity ($S(t)$) (gal)	Production level ($Pr(t)$) (gal)	Capacity Expansion for Next Year ($A(t)$) (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	100,000,000	220,735,570
2013	200,000,000	193,658,935	0	417,335,969
2014	200,000,000	200,000,000	0	298,462,400
2015	200,000,000	200,000,000	0	184,110,831
2016	200,000,000	200,000,000	0	84,930,568

Margin Changes: +20%				
Year (t)	Capacity $(S(t))$ (gal)	Production level $(Pr(t))$ (gal)	Capacity Expansion for Next Year $(A(t))$ (gal)	$f(S(t))$ ($)
2012	100,000,000	100,000,000	100,000,000	297,971,280
2013	200,000,000	193,658,935	0	495,642,275
2014	200,000,000	200,000,000	0	356,501,793
2015	200,000,000	200,000,000	0	221,675,422
2016	200,000,000	200,000,000	0	103,188,927

Appendix C: Capacity Expansion Analysis for Plant

Demand	Margin	2012	2013	2014	2015	2016
-40%	-40%	0	0	0	0	0
-40%	-30%	0	0	0	0	0
-40%	-20%	0	0	0	0	0
-40%	-10%	0	0	0	0	0
-40%	0%	0	0	0	0	0
-40%	10%	0	0	0	0	0
-40%	20%	0	0	0	0	0
-40%	30%	0	0	0	0	0
-40%	40%	0	0	0	0	0
-30%	-40%	0	0	0	0	0
-30%	-30%	0	0	0	0	0
-30%	-20%	0	0	0	0	0
-30%	-10%	0	0	0	0	0
-30%	0%	0	0	0	0	0
-30%	10%	0	0	0	0	0
-30%	20%	0	0	0	0	0
-30%	30%	50,000,000	0	0	0	0
-30%	40%	50,000,000	0	0	0	0
-20%	-40%	0	0	0	0	0
-20%	-30%	0	0	0	0	0
-20%	-20%	0	0	0	0	0
-20%	-10%	50,000,000	0	0	0	0
-20%	0%	50,000,000	0	0	0	0
-20%	10%	50,000,000	0	0	0	0
-20%	20%	50,000,000	0	0	0	0
-20%	30%	50,000,000	0	0	0	0
-20%	40%	50,000,000	0	0	0	0
-10%	-40%	0	0	0	0	0
-10%	-30%	50,000,000	0	0	0	0
-10%	-20%	50,000,000	0	0	0	0
-10%	-10%	50,000,000	0	0	0	0
-10%	0%	50,000,000	0	0	0	0
-10%	10%	50,000,000	0	0	0	0
-10%	20%	50,000,000	0	0	0	0
-10%	30%	50,000,000	0	0	0	0
-10%	40%	50,000,000	0	0	0	0

Demand	Margin	2012	2013	2014	2015	2016
0%	-40%	0	0	0	0	0
0%	-30%	50,000,000	0	0	0	0
0%	-20%	50,000,000	0	0	0	0
0%	-10%	50,000,000	0	0	0	0
0%	0%	50,000,000	0	0	0	0
0%	10%	50,000,000	0	0	0	0
0%	20%	100,000,000	0	0	0	0
0%	30%	100,000,000	0	0	0	0
0%	40%	100,000,000	0	0	0	0
10%	-40%	50,000,000	0	0	0	0
10%	-30%	50,000,000	0	0	0	0
10%	-20%	100,000,000	0	0	0	0
10%	-10%	100,000,000	0	0	0	0
10%	0%	100,000,000	0	0	0	0
10%	10%	100,000,000	0	0	0	0
10%	20%	100,000,000	0	0	0	0
10%	30%	100,000,000	0	0	0	0
10%	40%	100,000,000	0	0	0	0
20%	-40%	0	0	0	0	0
20%	-30%	100,000,000	0	0	0	0
20%	-20%	100,000,000	0	0	0	0
20%	-10%	100,000,000	0	0	0	0
20%	0%	100,000,000	0	0	0	0
20%	10%	100,000,000	0	0	0	0
20%	20%	100,000,000	0	0	0	0
20%	30%	100,000,000	0	0	0	0
20%	40%	100,000,000	0	0	0	0
30%	-40%	0	0	0	0	0
30%	-30%	100,000,000	0	0	0	0
30%	-20%	100,000,000	0	0	0	0
30%	-10%	100,000,000	0	0	0	0
30%	0%	100,000,000	0	0	0	0
30%	10%	100,000,000	0	0	0	0
30%	20%	100,000,000	50,000,000	0	0	0
30%	30%	100,000,000	50,000,000	0	0	0
30%	40%	100,000,000	50,000,000	0	0	0
40%	-40%	0	0	0	0	0
40%	-30%	100,000,000	0	0	0	0
40%	-20%	100,000,000	0	0	0	0

Demand	Margin	2012	2013	2014	2015	2016
40%	-10%	100,000,000	50,000,000	0	0	0
40%	0%	100,000,000	50,000,000	0	0	0
40%	10%	100,000,000	50,000,000	0	0	0
40%	20%	100,000,000	50,000,000	0	0	0
40%	30%	100,000,000	50,000,000	0	0	0
40%	40%	100,000,000	50,000,000	0	0	0

Appendix D: Total Profit of the Plant

D \ M	-40%	-30%	-20%	-10%	0%	10%	20%	30%	40%
-40%	23,468,818	72,340,838	121,212,858	170,084,878	218,956,899	267,828,919	316,700,939	365,572,959	414,444,979
-30%	9,801,662	52,777,076	95,752,490	138,727,904	181,703,318	224,678,733	267,654,147	324,590,655	382,613,362
-20%	(11,115,438)	23,313,818	57,743,074	117,432,454	180,259,732	243,087,011	305,914,290	368,741,568	431,568,847
-10%	(32,032,538)	(4,265,263)	59,759,195	123,783,652	187,808,110	251,832,568	315,857,026	379,881,484	443,905,942
0%	(52,949,637)	(29,883,139)	26,657,711	83,198,562	139,739,412	196,280,262	258,483,405	330,919,828	403,356,251
10%	(73,866,737)	(59,346,397)	(11,134,237)	66,106,758	143,347,754	220,588,750	297,829,746	375,070,741	452,311,737
20%	(94,783,837)	(88,207,272)	(10,971,562)	66,264,149	143,499,859	220,735,570	297,971,280	375,206,991	452,442,701
30%	(115,700,937)	(112,543,354)	(42,437,067)	27,669,219	97,775,506	167,881,792	243,203,231	327,864,464	412,525,698
40%	(136,618,036)	(142,006,611)	(80,446,483)	(7,633,285)	77,924,156	163,481,597	249,039,038	334,596,479	420,153,920

D: Demand changes   M: Margin changes

Appendix E. Total Profit of Nebraska Ethanol Industry

D \ M	-40%	-30%	-20%	-10%	0%	10%	20%	30%	40%
-40%	3,001,505,384	4,217,337,939	5,433,170,494	6,649,003,049	7,864,835,604	9,080,668,159	10,296,500,714	11,512,333,269	12,728,165,824
-30%	3,817,845,849	5,236,317,163	6,654,788,477	8,073,259,791	9,491,731,105	10,910,202,419	12,328,673,733	13,747,145,047	15,165,616,362
-20%	4,634,186,313	6,255,296,386	7,876,406,460	9,497,516,533	11,118,626,606	12,739,736,680	14,360,846,753	15,981,956,826	17,603,066,899
-10%	5,125,064,192	6,921,218,328	8,717,372,463	10,521,804,413	12,342,989,098	14,165,428,851	15,989,177,684	17,812,926,516	19,636,675,349
0%	5,271,233,605	7,268,769,714	9,266,305,824	11,263,841,933	13,261,378,042	15,258,914,151	17,256,450,261	19,253,986,370	21,251,522,479
10%	5,203,008,209	7,303,862,914	9,404,717,618	11,505,572,322	13,606,427,026	15,707,281,731	17,808,136,435	19,914,199,761	22,030,767,073
20%	5,134,782,814	7,338,956,113	9,547,399,993	11,780,064,765	14,012,729,536	16,245,394,308	18,478,059,080	20,710,723,851	22,943,388,623
30%	4,776,160,890	7,034,324,271	9,304,953,866	11,575,583,460	13,846,213,055	16,116,842,649	18,387,472,243	20,658,101,838	22,928,731,432
40%	4,450,105,059	6,748,823,449	9,047,541,838	11,346,260,227	13,644,978,616	15,948,886,495	18,266,778,415	20,584,670,335	22,902,562,254

D: Demand changes   M: Margin changes

Appendix F: Capacity Expansion Analysis for Nebraska

Demand	Margin	2012	2013	2014	2015	2016
-40%	-40%	0	0	0	0	0
-40%	-30%	0	0	0	0	0
-40%	-20%	0	0	0	0	0
-40%	-10%	0	0	0	0	0
-40%	0%	0	0	0	0	0
-40%	10%	0	0	0	0	0
-40%	20%	0	0	0	0	0
-40%	30%	0	0	0	0	0
-40%	40%	0	0	0	0	0
-30%	-40%	0	0	0	0	0
-30%	-30%	0	0	0	0	0
-30%	-20%	0	0	0	0	0
-30%	-10%	0	0	0	0	0
-30%	0%	0	0	0	0	0
-30%	10%	0	0	0	0	0
-30%	20%	0	0	0	0	0
-30%	30%	0	0	0	0	0
-30%	40%	0	0	0	0	0
-20%	-40%	0	0	0	0	0
-20%	-30%	0	0	0	0	0
-20%	-20%	0	0	0	0	0
-20%	-10%	0	0	0	0	0
-20%	0%	0	0	0	0	0
-20%	10%	0	0	0	0	0
-20%	20%	0	0	0	0	0

Demand	Margin	2012	2013	2014	2015	2016
-20%	30%	0	0	0	0	0
-20%	40%	0	0	0	0	0
-10%	-40%	0	100,000,000	0	0	0
-10%	-30%	0	100,000,000	0	0	0
-10%	-20%	0	100,000,000	0	0	0
-10%	-10%	0	100,000,000	0	100,000,000	0
-10%	0%	0	100,000,000	0	100,000,000	0
-10%	10%	0	100,000,000	100,000,000	0	0
-10%	20%	0	100,000,000	100,000,000	0	0
-10%	30%	0	100,000,000	100,000,000	0	0
-10%	40%	0	100,000,000	100,000,000	0	0
0%	-40%	200,000,000	100,000,000	100,000,000	0	0
0%	-30%	200,000,000	100,000,000	100,000,000	0	0
0%	-20%	200,000,000	100,000,000	100,000,000	0	0
0%	-10%	200,000,000	100,000,000	100,000,000	0	0
0%	0%	200,000,000	100,000,000	100,000,000	0	0
0%	10%	200,000,000	100,000,000	100,000,000	0	0
0%	20%	200,000,000	100,000,000	100,000,000	0	0
0%	30%	200,000,000	100,000,000	100,000,000	0	0
0%	40%	200,000,000	100,000,000	100,000,000	0	0
10%	-40%	400,000,000	100,000,000	100,000,000	0	0
10%	-30%	400,000,000	100,000,000	100,000,000	0	0
10%	-20%	400,000,000	100,000,000	100,000,000	0	0
10%	-10%	400,000,000	100,000,000	100,000,000	0	0
10%	0%	400,000,000	100,000,000	100,000,000	0	0
10%	10%	400,000,000	100,000,000	100,000,000	0	0
10%	20%	400,000,000	100,000,000	100,000,000	0	0
10%	30%	400,000,000	100,000,000	100,000,000	100,000,000	0

Demand	Margin	2012	2013	2014	2015	2016
10%	40%	400,000,000	100,000,000	100,000,000	100,000,000	0
20%	-40%	600,000,000	100,000,000	100,000,000	0	0
20%	-30%	600,000,000	100,000,000	100,000,000	0	0
20%	-20%	600,000,000	100,000,000	100,000,000	100,000,000	0
20%	-10%	600,000,000	100,000,000	100,000,000	100,000,000	0
20%	0%	600,000,000	100,000,000	100,000,000	100,000,000	0
20%	10%	600,000,000	100,000,000	100,000,000	100,000,000	0
20%	20%	600,000,000	100,000,000	100,000,000	100,000,000	0
20%	30%	600,000,000	100,000,000	100,000,000	100,000,000	0
20%	40%	600,000,000	100,000,000	100,000,000	100,000,000	0
30%	-40%	600,000,000	400,000,000	0	0	0
30%	-30%	600,000,000	400,000,000	100,000,000	0	0
30%	-20%	600,000,000	400,000,000	100,000,000	0	0
30%	-10%	600,000,000	400,000,000	100,000,000	0	0
30%	0%	600,000,000	400,000,000	100,000,000	0	0
30%	10%	600,000,000	400,000,000	100,000,000	0	0
30%	20%	600,000,000	400,000,000	100,000,000	0	0
30%	30%	600,000,000	400,000,000	100,000,000	0	0
30%	40%	600,000,000	400,000,000	100,000,000	0	0
40%	-40%	600,000,000	600,000,000	100,000,000	0	0
40%	-30%	600,000,000	600,000,000	100,000,000	0	0
40%	-20%	600,000,000	600,000,000	100,000,000	0	0
40%	-10%	600,000,000	600,000,000	100,000,000	0	0
40%	0%	600,000,000	600,000,000	100,000,000	0	0
40%	10%	600,000,000	600,000,000	100,000,000	100,000,000	0
40%	20%	600,000,000	600,000,000	100,000,000	100,000,000	0
40%	30%	600,000,000	600,000,000	100,000,000	100,000,000	0
40%	40%	600,000,000	600,000,000	100,000,000	100,000,000	0