COMPARING GENETIC MODIFICATION AND GENETIC EDITING TECHNOLOGIES:

MINIMAL REQUIRED ACREAGE

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Comparing Genetic Modification and Genetic Editing Technologies:
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ABSTRACT

There are many technologies being developed for crop breeding. Two interesting technologies are genetic modification and genetic editing. Competitive pressures and changing consumer preferences are forcing organizations to invest heavily into these two technologies. Organizations must decide which traits they want to target and must commit significant time a money to the project. Traditionally, firms would decide which project to embark on if the project is net present value positive. Throughout the research and development process managers have flexibility to abandon the project once new information is received. That flexibility has value and real option analysis must be performed to value that flexibility. Once the value of a GM and GE project is determined, how might an organization decide which project to do? The concept of minimum required acreage (MRA) is developed in this study, allowing organizations to compare GM and GE technologies and decide which project to invest it.

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CHAPTER 1. INTRODUCTION

1.1. Overview

There are many technologies being developed for crop breeding. Two of the more interesting technologies enable genetic modification (GM or transgene insertion) and genetic editing (GE or non-transgene insertion) in crops. Both GM and GE processes are an alternative to conventional breeding programs but may be more expensive, time consuming and risky. GM and GE technologies give organizations the ability to (relative to conventional crop breeding programs) efficiently change the nutritional and or the economic value of crops. Competitive pressures and changing consumer preferences are forcing organizations to invest heavily into these two technologies. Organizations must decide which traits they want to target and then must commit significant time a money to the project. For this study, both public and private seed developers were surveyed so the costs and time commitment of GM and GE projects can be better understood. Traditionally, firms would decide which project to embark on if the project is net present value (NPV) positive. However, throughout the research and development process managers have flexibility to abandon the project once new information is received. That flexibility has value and is not reflected in NPV analyses. To gain a better understanding of a project's value, real option analysis must be performed. Once the value of a GM and GE project is determined, how might an organization decide which project to do? The concept of minimum required acreage (MRA) is developed in this study, allowing organizations to compare GM and GE technologies and thoughtfully decide which project to invest it.

This chapter highlights the risks of GM and GE crop development, objectives of this study, procedure, and organization of the paper.

1.2. Problem Statement

Organizations that develop different crop seed theoretically have an endless number of projects they could do. If an organization wishes to develop a new wheat seed, using either GM or GE technologies, how should they decided which projects to invest in? It's not clear if they should develop the new wheat seed using GM or GE technologies. The fundamental question that needs to be answered is: if a seed is developed using GM or GE processes, how much market share must be captured to make the project profitable?

1.3. Objectives

Genetic modification and genetic editing technologies are not completely substitutional technologies. Both are tools in the preverbal tool chest and can in some cases be used to produce the same end result. To make the best strategic decision possible, organizations need the ability to compare GM and GE projects. Organizations need to know how many acres are required to make the project's real option value (ROV) positive. The goal of this study is to compare both GM and GE technologies using real options analysis to then determine the minimum required acres need to make a GM and GE project profitable. The specific goals of this study are:

1. Create a model to value the abandonment option managers have in the research and development process.
2. Use the real option value for both GM and GE technologies to calculate the average minimum acres required to make both GM and GE projects profitable.
3. Conduct sensitivity analysis as to determine the main drivers of the required acres planted.

1.4. Procedures

Every seed developer has the right, but not the obligation, to abandon any seed project. After each developmental phase, seed developers can evaluate the environment and continue the project or abandon it, freeing capacity for other potentially profitable projects. The ability to abandon a project and start a new one after every developmental phase provides flexibility to any seed developer.

The MRA model is comprised of two smaller models. Model one is a net present value (NPV) model and model two is a stochastic binomial option pricing tree. Model one's function is to calculate the mean present value of expected cash flows from both GM and GE seed projects. Model two is a stochastic binomial option pricing tree which incorporates the value of the flexibility discussed above after every developmental phase.

In any given iteration of the simulation, the probability the seed developer should exercise the option and abandon the project is calculated. Therefore, the probability of exercising the option can be fixed and then the model can be optimized to solve for what market share must be captured to satisfy the fixed probability of exercising the option to abandon the project. In this study, the probability of abandonment was fixed at five percent, acres planted was then solved for (optimized) to determine the minimum required acreage (MRA) needed to make the real option value (ROV) equal zero, subject to all other stochastic variables in models one and two.

1.5. Organization

Chapter 2 of this paper provides an overview of GM technologies and the emergence of GE technologies. Chapter 3 will outline real option analysis in general and will also include a summary of studies that valued specific GM traits in crops using real options analysis. Chapter 4 provides an overview and detailed explanation of the MRA model's structure. Data regarding

GM and GE development are presented, and the distributions of that data is shown. Chapter 5 provides the base case results of the MRA model for both GM and GE projects. Sensitivity analysis is then discussed and the regression coefficients for the underlying variables are presented. Chapter 6 presents a summary of the study, its conclusions, implications, limitations, and recommendations for future research.

CHAPTER 2. GENETIC MODIFICATION AND GENETIC EDITING TECHNOLOGIES

2.1. Introduction

Seed developers interested in creating a new crop variety have many technologies at their disposal. Two technologies that are particularity interesting are genetic modification and genetic editing. This chapter provides an overview of genetic modification and genetic editing technologies.

2.2. Genetic Modification

Genetically modified plants are plant varieties that have been created by inserting another organism's DNA (transgene insertion) into the original plant's DNA. The Flavr Savt tomato, developed in 1994, is widely considered to be the first genetically modified crop that was approved for consumption. By 2015, it was estimated that genetically modified crops were grown on 445 million acres or 10% of earth's cultivable land.

There are two major DNA transfer methods utilized in the process of creating a new genetically modified plant variety. One, many metal particles are covered with the relevant DNA from some outside organism. The metal particles are then shot at many of the plant's original cells, with the hope that the plant will have successfully taken the DNA. The second major method is the agrobacterium tumefaciens method (ATM). Simply, relevant DNA is added to a bacterium with the hope that the bacterium can transfer the relevant DNA to the plant.

Both major methods utilized in the process of creating a new genetically modified plant variety are precise relative to other conventional breeding technologies. However, it is clear that genetic modification requires a great deal of luck and a substantial trial and error process. The high cost and overall length of development phases when creating a new GM variety is a result of the overall lack of precision in genetic modification technologies.

Regardless of its high cost and long developmental timeline, there are substantial benefits a new GM crop variety can provide. Genetically modified crops, on average, have increased yields by 22%, increased farmers by 68% and decreased the use of chemical pesticides by 37%.

2.3. Genetic Editing

Genetically edited plants are plant varieties that have been created by cutting out a part of a plant's DNA or editing a part of the plant's DNA (non-transgene insertion) or, more challenging, inserting the DNA of another organism into the original plant's DNA. Relative to genetic modification, genetic editing is a relatively new technology and advances in the technology are being still being made.

Like genetic modification, genetic editing technologies have multiple pathways that can be used to "edit" a plants genome. There are nine total genome editors as of 2017 with Meganucleases, Zinc Finger, TALEN, and CRISPER being to most popular. Unlike genetic modification processes, which depends on luck and trial and error, technologies such as CRISPER are very precise.

CRISPER can be programed to find a single DNA sequence that may be responsible for some negative trait in a plant and simply cut it out. Relative to the standard genetic modification processes, genetic editing is a far more precise tool. Because of luck and trial and error involved in genetic modification, it may take five or my cycles to achieve the intended result. Because of the precision of genetic editing, it takes only one or two cycles to achieve the intended result. Added precision is not the only positive result of gene editing. Because gene editing can change a plants genome without the use of another organism's DNA, gene edited plants may avoid current regulations that apply to genetically modified plants.

2.4. Summary

Seed developers interested in creating a new crop variety have many technologies at their disposal. Two technologies that are particularity interesting are genetic modification and genetic editing. The genetic modification process relies on luck and trial and error. The genetic editing process is analogous to a computer program where you can search for a DNA sequence, cut that particular sequence out and, if desired, can insert an entirely new DNA sequence. Because of greatly improved precision and the ability to change a genome without adding another organism's DNA, gene editing is a technology that can produce new crop varieties faster and cheaper.

Tools such as CRISPER or TALEN are relatively new, so new that few companies have commercialized a genetically edited crop. Genetically modified crops have been shown to have positive impacts on agronomics and farm economics and are planted on millions of acres every year.

Genetic editing promises to drag down the cost and speed up the developmental of new crop varieties. There is big money at stake and many paths can be taken to develop new crop varieties. Given genetic modification and genetic editing are the leading technologies today, this study compares the technologies and presents a risk framework that can help seed developers choose a path.

CHAPTER 3. REAL OPTION ANALYSIS: BACKGROUND AND PRIOR STUDIES

There are two elements to every investment, a quantitative element and qualitative element (Dixit and Pindyck 1994). The quantitative elements are variables such as sales, costs, and profits. The quantitative elements of an investment are easy to recognize and traditional valuation methods such as net present value (NPV) or discounted cash flow (DCF) analysis are effective quantitative valuation tools.

Qualitative elements of an investment are variables such as managerial flexibility and timing, both of which may be harder to recognize relative to familiar quantitative variables. Most capital investments are not a result of a single, static decision or strategy. Rather, they are a summation of many decisions made over time which were dependent on the business environments faced along the way. Management teams have flexibly during the investment process and flexibility itself has value (Trigeorgis 1996). Real option analysis (ROA) can be an effective tool in understanding the value of the qualitative elements in some investments.

3.1. Real Option Overview

Most capital investments have some degree of risk and uncertainty. Because most capital investments are done in stages, managers are able to survey the business environment every time period and adjust their capital investment strategies accordingly. The uncertainty of future business environments and investment timing are qualitative variables in the investment process. Uncertainty is a variable that effects future cash flows of an investment, dramatic increases or decreases in future earnings has major effects on the return on investment. The timing of an investment decision also has an effect on the return on investment. If a business is able to pause during the investment process and gain a deeper understanding of the current and future business environment, uncertainty can be lowered. Uncertainty of the future and the flexibility to change investment decisions accordingly determines the return on investment (Dixit and Pindyck 1994).

3.1.1. ROA vs. NPV

Real options analysis is a methodology that can be used to estimate an investments value by accounting for investment flexibility and uncertainty. ROA, NPV, and DCF methodologies are all viable valuation techniques (Turvey 2001), each of which has its benefits and drawbacks. NPV and DCF analysis are powerful tools if there is high certainty of the future. If cash flows can be accurately estimated and there is little uncertainty in the future, either valuation technique produces an accurate representation of the value of the investment. In reality, there is often a low certainty of the future and cash flows cannot be accurately estimated with much precision. Because of high uncertainties, especially in investment decisions that are drawn out over years, managers have flexibility to adjust their investment strategies over time which can be impactful to the investment's overall performance (Dixit and Pindyck 1994). The inability for NPV or DCF methodologies to capture management flexibility and dynamic investment strategies (Trigeorgis 1996) is a drawback and suggests these valuation techniques may underestimate the value of certain investments.

Real option analysis on the other hand does capture management flexibility and dynamic investment strategies. As uncertainty increases in an investment, the difference in valuations between NPV and ROA increases because NPV techniques are unable to account for volatility (Alizadah and Nomikos 2009). When there is high uncertainly in the future and cash flows cannot be accurately predicted the investment should be valued with ROA, not NPV techniques which do not account for uncertainty, management flexibility, and dynamic strategies (Turvey 2001).

3.1.2. Real Options vs. Financial Options

Real options are similar to financial options with the nuance that a real option is applied to a real or non-financial asset. Like financial options, there are call and put real options. Call options give the owner the right, not obligation, to buy the underlying financial asset at some price. Likewise, a put option gives the owner the right, not obligation, to sell the underlying financial asset at some price.

Real call and put options are similar to financial call and put options. In ROA, a call option gives a management team the right, not obligation, to survey some investment opportunity. If the opportunity appears profitable, the management team could exercise the call option and invest in the opportunity. Management can also own a put option which gives the right, not obligation, to abandon the opportunity if the project appears unprofitable.

3.2. Calculating Real Option Value Methods

Generally, there are three methods used to calculate real option values: Monte Carlo simulation, dynamic programming, and differential equations (Amram and Kulatilaka 1999). Monte Carlo simulations utilize stochastic processes and can estimate the value of many input variables in a model. The simulation of every variable can be constrained by different distributions to control variable behavior. The value of each variable can be simulated tens-of-thousands of times with respect to the imposed distributions, resulting in an average output value of all simulated scenarios. The output value can then be discounted to its present value. Simulations, in general, are useful tools when calculating real option values because they can be used independently or in conjunction with other valuing techniques.

Dynamic programming (binomial trees) is a technique where many different outcomes of the same project are discounted back to its present value. Starting in time equals zero, an investment project can move “up or down” in each subsequent time period as a result of volatility and probability. Every value at each node can be discounted back to its present value and used to determine option value based on which scenario one finds themselves in. This study uses both dynamic programming and Monte Carlo simulation.

Lastly, option values can be estimated using partial differential equations. The Black-Scholes model is a popular example. Black-Sholes is a simple to use model and requires just five inputs: volatility, risk-free rate, time to expiration, costs, and the assets price. While easy to use, the Black-Sholes model is not particularly useful for American styled options and scenarios that stretch far into the future.

3.3. Methods Relevant to this Study

This section discusses the type of option and option valuation technique used in this study. The first section outlines why an abandonment option is used. The second section is a discussion on the Monte Carlo binomial option pricing model.

3.3.1. Abandonment Option

This study assumes seed developers can successfully create a new crop variety every time they try and their decision to do so is purely economical, meaning the developing organization w develops a new variety if the project is profitable. More specifically, the study models an organization that can make a new crop variety any time it chooses subject to a positive return as measured by a positive real option value. If a project costs too much or takes too long (negative real option value), the organization would choose to abandon the project. To best compare GM and GE technologies, the above assumption was made, and the abandonment option was chosen.

An abandonment option allows the developing organization the flexibility to avoid additional losses. Figure 3.1. shows the payoff function for an abandonment option. As the present value of cash flows falls and then goes negative, the option to abandon is in the money and could be exercised. The option to abandon grants its owner the right, but not the obligation, to sell the asset (tangible or intangible) and can be modeled as a put option (Winston 2008, Alizadeh and Nomikos 2009).

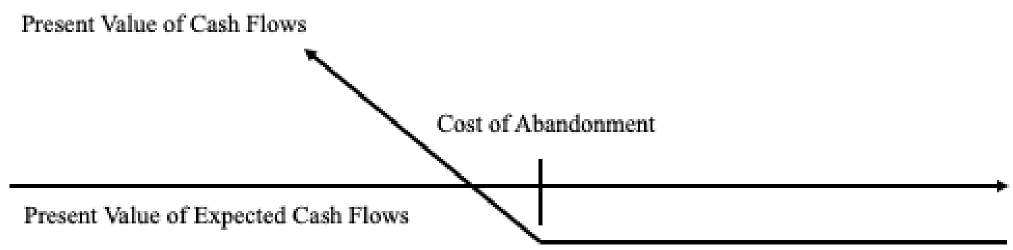

Figure 3.1. Abandonment Option Payoff

3.3.2. Binomial Option Pricing Model

Cox, Ross, and Rubinstein (1979) first proposed the binomial option pricing model and it has since become a popular technique for option pricing. The model itself requires just three data inputs: a risk-free rate (r), volatility (σ), and an asset value. The model assumes an option is made up of many time periods (t), both discrete and equal and that the option value follows a binomial path. At each time period, the option value can increase or decrease with respect to up (u) and down (d) factors. The up and down factors are determined by the asset's price volatility, risk-free rate, and probabilities of a move up or down.

When the asset's value, volatility, and risk-free rate are known variables, the up and down factors and probabilities can be calculated as follows:

$$u = e^{\sigma * \sqrt{\Delta t}}$$

$$d = \frac{1}{u}$$

$$p = \frac{e^{r * \Delta t} - d}{u - d}$$

Beginning with the assets initial value, the first branch of a binomial tree can be created as in figure 3.1.

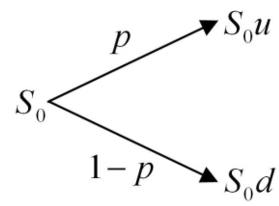

Figure 3.2. Generic One-Step Lattice Tree

The process in figure 3.2. is then repeated to create all branches for all time periods. After the binomial tree has been completed, the option payoff can be calculated at every node in the binomial tree. Payoffs for call and put options are defined as follows:

$$V_N Call = Max\ (S_N - X, 0)$$

$$V_N Put = Max\ (X - S_N, O)$$

Where V_N is the option value at each node, X is the strike price, and S_N is the underlying price of the asset at expiration.

Finally, by backward induction, all node payoff values, starting at the penultimate node and working backward sequentially, are discounted to their present value as follows:

$$V_N = \ e^{-r*\Delta t}(p * V_u + (1-p) * V_d)$$

where V_u and $V_d$are the option values of the up and down movements at each time period.

3.4. Real Option Analysis in Prior Studies

3.4.1. Early Real Option Studies

McDonald and Seigel (1985) were among the first to demonstrate option pricing theory could be applied to a firm when variable costs were greater than expected revenues. When variable costs exceed expected revenues, firms can halt production which is analogous to exercising a put option. Later, Pindyck (1988) suggested the timing of an investment could be considered and option. A frim can decided to undertake an investment immediately or it can choose to wait. At any point in time, when the decision is ultimately made to move forward with the investment, the firm has exercised an option.

3.4.2. Real Options in Agriculture Relating to this Study

Real option analysis has been utilized in the agricultural sector increasingly over the past few decades. Turvey (2000) observed agribusiness firms encountered many real options during an investment decision including learning options and options to expand. Churchill (2016) identified eight different real option were commonly used in biotech license agreement contracts. Shakya, Wilson, and Dahl (2012) used real options to find genetically modified (GM) wheat would potentially be more valuable in the Prairie Gateway and the northern Great Planes regions in the United States. Lastly, Wynn (2017) used real options to show the development of drought tolerant canola is more profitable in some regions of Australia and not in others.

It has been shown real option analysis is a valuable tool for evaluating investment decisions in the agricultural sector. No study, to date, has used real option analysis to compare genetic modification (GM) and genetic editing (GE) technologies on the same crop.

3.5. Conclusion

This chapter outlines investment decisions are complex and dependent on many variables. Traditional valuation techniques such as discounted cash flow (DFC) or net present value (NPV) models are relatively static in comparison to real option analysis (ROA). Real option analysis has gained popularity because of its ability to be model the dynamic investment decision making process. When a firm is deciding how to spend limited time and resources, they must have the tools at their disposal to properly evaluate their alternatives.

In this study, genetic modification and genetic editing technologies were compared using real option analysis. Specifically, binomial lattice trees and Monte Carlo simulation techniques were used to value and compare genetic modification and genetic editing projects by determining how much market share (acres) would be required to achieve a profitable investment form each technology.

CHAPTER 4. MINIMUM REQUIRED ACREAGE EMPIRICAL MODEL

4.1. Introduction

Seed developers must carefully estimate how much market penetration is required to make any given project viable. Genetic modification (GM) and genetic editing (GE) have very different cost and time requirements. As such, the market penetration needed for each, or the minimum required acreage (MRA) to make the project viable, can be very different. The heart of the MRA model is an abandonment real option. Seed developers face two outcomes scientifically with every project, either the project passes each phase of development and goes to market or the project is abandoned. This chapter provides an overview of the empirical model for calculating the MRA, inputs, distributions of inputs, and data sources.

4.2. Basic Model Overview

The MRA model can be best described as two models in one. Model one is a simple NPV model and model two is a binomial option tree. Simply, the gross present value of expected cash flows comes out of the NPV model and dumps into the binomial option tree. Then, based on the simulation of underlying variables, the MRA is calculated by how many acres is required to make the probability of excessing the option 5%.

The MRA model outlined above applies only to seed developers selling into the North Dakota wheat market because geography has little effect on cost but a large effect on revenues. This model assumes that some seed developer developers a seed over some amount of time and cost, then sells the newly developed seed to farmers for some price. The outline above is applied to both a genetically modified seed and genetically edited seed.

4.3. Detailed Elements of Model

The first step in the MRA model is determining the time and cost of development for both GM and GE seed projects. Both GM and GE seed projects have a discovery phase and three addition developmental phases. In this study, GM seed projects have a fourth phase which encompasses regulation time and costs. For simplicity, GE is lightly regulated in this model and is represented in the third phase. The derivation of the time and cost of development is as follows:

$$Time\ of\ Developemt = T = DT + P_iT$$

$$Cost\ of\ Development = C = DC + P_iC$$

where T is time, C is cost, DT is the discovery phase time of development, DC is the cost of the discovery phase, PiT is the time of development for the phase, PiC is the cost of the phase, i, where i =1,…,4

After the time and cost of development is determined for both GM and GE seed projects, gross profit must be determined. Keep in mind that revenues are received in the time period after development is completed. The derivation of gross profit is as follows:

$$Gross\ Profit = GP = AP * R * Gm$$

where GP is gross profit, AP is acres planted, R is revenues per acres, and Gm is gross margin.

After gross profit is determined for both GM and GE seed projects, the gross present value of expected gross profit (PvGP) must be determined. The derivation of the PvGP is as follows:

$$PvGP = \sum_{t=1}^{n} \frac{C_t}{(1+i)^t}$$

where C_t is gross profit in period t, i is rate of interest, and n is number of years discounting. Calculating the PvGP is the final step with regards to model one, the NPV model.

Up and down factors must then be calculated. The derivation of the up and down factors is as follows:

$$u = e^{(\sigma\sqrt{\delta t})}$$

$$d = e^{(-\sigma\sqrt{\delta t})} = \frac{1}{u}$$

where δt is the time associated with each time step of the binomial tree, and σ is volatility (%) defined as the standard deviation of the natural logarithm of all gross profits.

After the up and down factors are determined, the risk-neutral probability must be determined. The derivation of the risk-neutral probability, p, is as follows:

$$p = \frac{e^{r\delta t} - d}{u - d}$$

where r is the risk-free rate.

Now the binomial tree can be constructed using the previous equations. The initial node of the tree, S_0, is the PvGP as calculated above. Utilizing both the up and down factors, S_0u^4 and S_0d^4 were calculated for the GM seed project and S_0u^3 and S_0d^3 were calculated for the GE see project.

After the asset values at each node are determined, the option value at each node is calculated by backward induction from the terminal node:

$$[p(S_0u^n) + (1-p)(S_0u^{n-1}d)] * e^{-r\delta t}$$

where backward induction is applied to all nodes in both GM and GE seed development option trees. Salvage value at each node must also be calculated.

In this study, salvage value (Sv) is 20% of the total cost of development of all-time steps completed. The probability of exercising the abandonment option is calculated as follows:

$$NSv/2^n$$

where NSv is the sum of all nodes in which the salvage value was greater than the option value, and n is the total amount of time steps in the binomial tree model.

$NSv/2^n$ was optimized using Risk Optimizer in @Risk. Specifically, the probability of abandoning the project for both GM and GE seed projects was calculated by allowing various input variables to change within a given distribution and optimizing for how many acres are needed to make the probability of abandoning the projects 10%, 5% and 1%.

4.4. Data Sources

All data used for this study came from interviews with industry experts and/or surveys answered by industry experts. Because of the sensitivity of the data, all survey respondents are kept anonyms. Table 4.1. shows the estimated probability of success by phase, estimated cost range of each phase in millions of dollars, and the estimated development time of each phase in years for both GM and GE projects.

Table 4.1. GM / GE Survey Data

Genetic Modification (GM)

Phase	Probability of Success	Cost ($Millions)	Phase Development Time (Years)
D	5%	2-8	1
P1	25%	5-12	1-2
P2	50%	10-18	1-2
P3	75%	15-40	1-2
P4	90%	20-50	2-3

Genetic Editing (GE)

Phase	Probability of Success	Cost ($Millions)	Phase Development Time (Years)
D	25%	2-6	1
P1	50%	2-6	1-2
P2	75%	2-6	1-2
P3	90%	2-6	1-2

4.5. Model Setup and Distributions

The only fixed variables in the model are the discount rate and risk-free rate which were set at 15% and 3% respectfully. All other variables were either stochastic and bounded by distributions or derived during the simulation. Table 4.2. shows the model setup for the base case.

Table 4.2. Base Case Inputs & Distributions

Variable	Category	Distribution (GM)	Distribution (GE)
D (Years)	Fixed	1	1
P1 (Years)	Stochastic	RiskTriangle (1,1.5,2)	RiskTriangle (1,1.5,2)
P2 (Years)	Stochastic	RiskTriangle (1,1.5,2)	RiskTriangle (1,1.5,2)
P3 (Years)	Stochastic	RiskTriangle (1,1.5,2)	RiskTriangle (1,1.5,2)
P4 (Years)	Stochastic	RiskTriangle (2,2.5,3)	N/A
D (Cost $M)	Stochastic	RiskTriangle (2,3.5,8)	RiskTriangle (2,3,6)
P1 (Cost $M)	Stochastic	RiskTriangle (5,7.5,12)	RiskTriangle (2,3,6)
P2 (Cost $M)	Stochastic	RiskTriangle (10,12.5,18)	RiskTriangle (2,3,6)
P3 (Cost $M)	Stochastic	RiskTriangle (15,22.5,40)	RiskTriangle (2,3,6)
P4 (Cost $M)	Stochastic	RiskTriangle (20,30,50)	N/A
Rev per Acre	Stochastic	RiskTriangle (12.04,17.39,22.73)	RiskTriangle (12.04,17.39,22.73)
Gross Margin	Stochastic	RiskTriangle (0.4,0.5,0.6)	RiskTriangle (0.4,0.5,0.6)

Variables D through P4 represent a specific phase in the development process. D is simply the discovery phase and P1-P4 are generic names for phase 1 through phase 4 of development. Volatility, time steps, up and down factors, risk-neutral probabilities and salvage values are all derived once the simulation is running because each are dependent on the variables in table 4.1.

It was assumed that organizations would be able to sell their newly developed seed for 15 years with an average price that can vary, subject to a distribution. Sales would begin in the first time period after the end of development and continue for 15 years. Risk Optimizer was used to determine how many acres are needed, subject to the variables above, by solving for the acreage required to make the probability of abandoning the project 5%.

4.6. Summary

This chapter summarized the empirical model for determining the minimum required acreage needed to make a GM and GE seed project viable, stochastic and fixed inputs, and data sources. The core of the model, but not the focus, is a real option model which was used to determine the probability that an organization would abandon a seed development project at some point in the development process.

CHAPTER 5. RESULTS

5.1. Introduction

To better understand the economics of GM and GE seed development, a real option model was created to simulate an environment a seed developer may face selling into the North Dakota seed market. Developers have a choice at the end of each developmental phase to either continue with the project or abandon it. To understand the MRA for potential GM and GE seed projects, the probability of abandonment was fixed at 5% and the model was optimized using Risk Optimized in @Risk.

Sensitivity analysis was conducting where revenue per acre, discount rates, and probability of abandonment varied from $17.39 to $22.50, 12% to 19%, and 1% to 10% respectively. Regression coefficients are shown stochastic variables in all scenarios in the sensitivity analysts.

5.2. Base Case Results

The base case for determining the MRA for GM and GE seed projects assumes a 15% discount rate, 3% risk free rate, an average revenue per acre of $17.39, and a 5% probability the seed developer would exercise the option to abandon the project. Using @Risk's Risk Optimizer, results show the MRA to make GM and GE seed projects viable is 7,016,223 acres and 857,633 acres respectively. To be viable, an average GM seed project would need to capture 8.18 times the number of acres relative to a GE seed project.

Figures 5.1 shows, according to regression coefficients, that the developmental time of phase 1 through phase 4 has the largest impact on the acres needed to make GM seed projects a viable one. Costs in the third and fourth phase also has a large impact on the acres required to make the project viable.

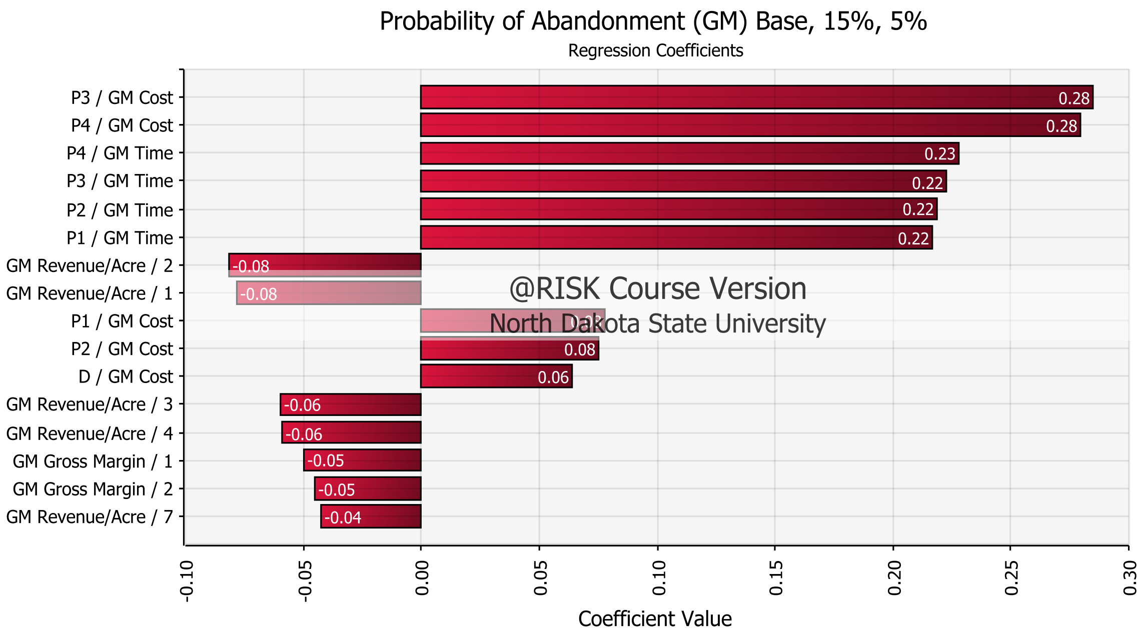

Figure 5.1. Base Case GM Results

Figure 5.2 shows, according to regression coefficients, that developmental costs had by far the largest impact on the acres needed to make a GE seed projects viable. Acreage need to make the project viable was less sensitive to time of development.

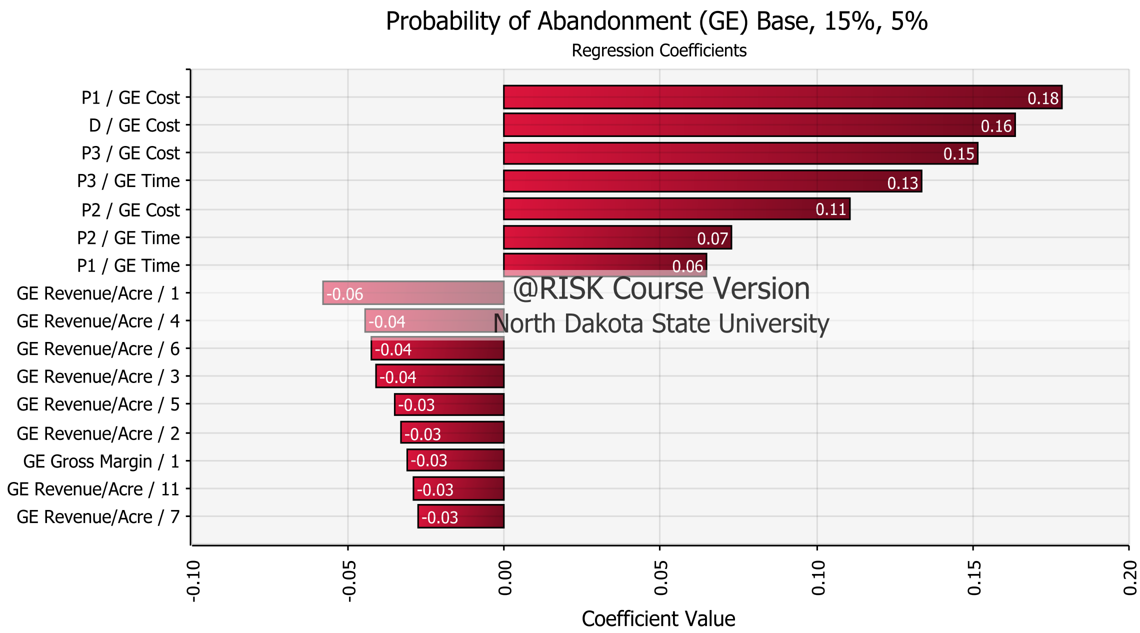

Figure 5.2. Base Case GE Results

5.3. Sensitivity Analysis of Stochastic Variables

In addition to the base case, revenue per acres, discount rate, and confidence intervals were all varied to gain a better understanding of the relationship between probability of abandonment and acreage needed.

5.3.1. Revenue Per Acre

In the base case, it was assumed that the revenue per acre was $17.39. If organizations could increase their seed price by ~15% to $20, the MRA falls for both GM and GE seed projects ~13% to 6,038,243 acres and 742,924 acres respectfully. Figure 5.3 and 5.4 shows the regression coefficients of stochastic variables for GM and GE seed projects when revenue per acre is $20.

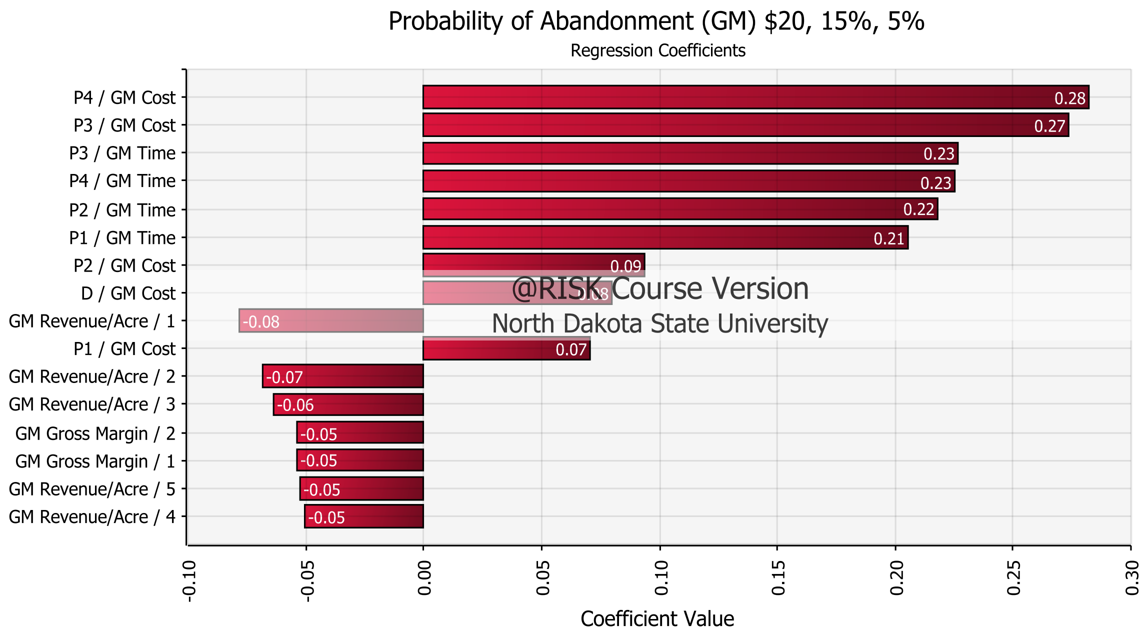

Figure 5.3. GM Results / $20 Price

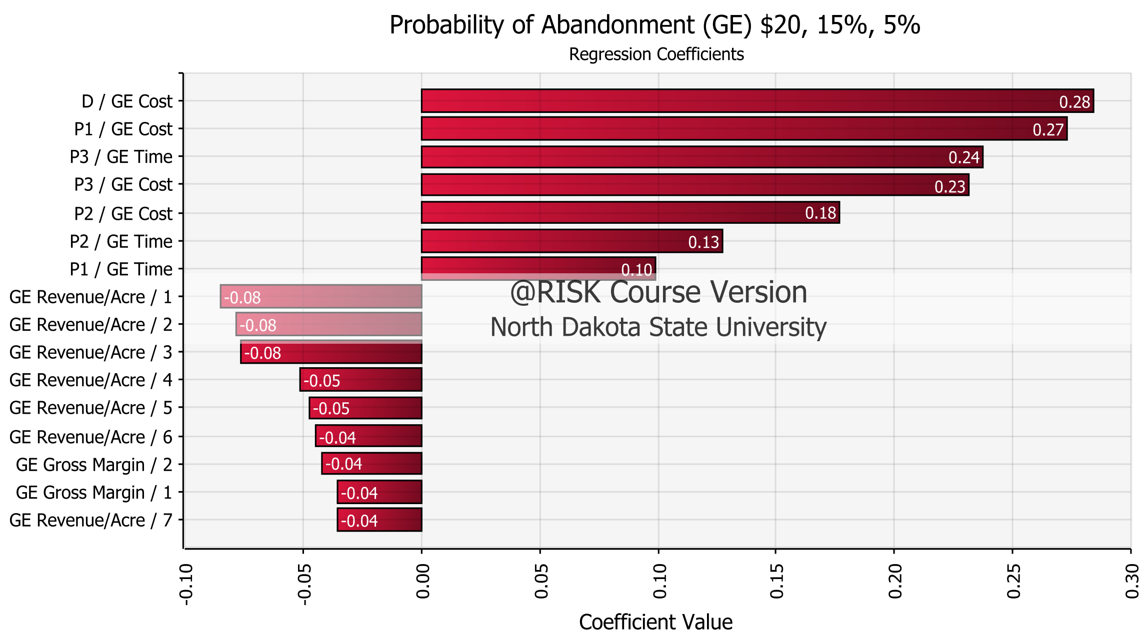

Figure 5.4. GE Results / $20 Price

Little has changed when revenue per acre increased from $17.39 to $20 per acre. Both GM and GE seed developers would need to be very focused on the time and cost of each developmental phase of the project.

If organizations could increase seed prices ~30% to $22.5, the MRA falls for both GM and GE seed projects ~23% to 5,390,945 acres and 658,280 acres respectfully. Figure 5.5 and 5.6 shows the regression coefficients of stochastic variables for GM and GE seed projects when revenue per acre is $22.50.

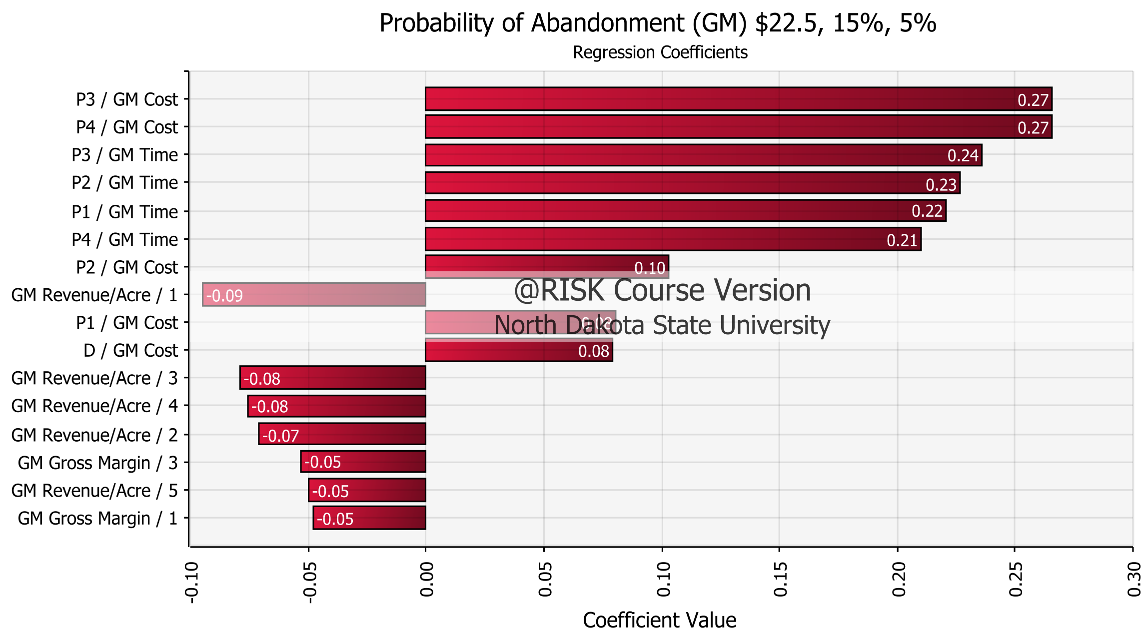

Figure 5.5. GM Results / $22.50 Price

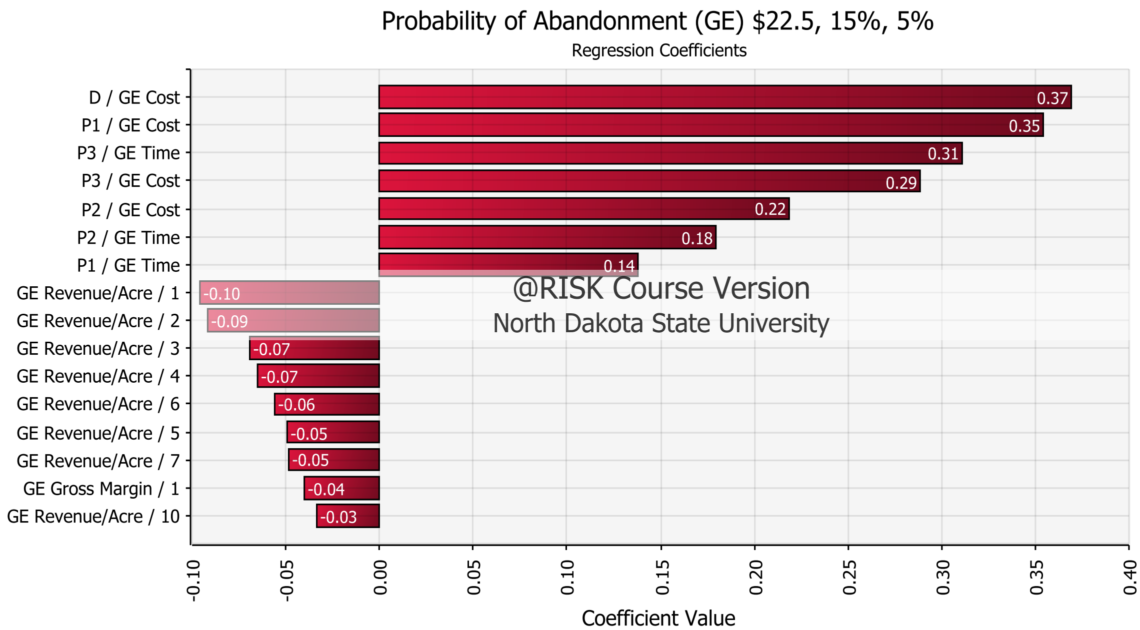

Figure 5.6. GE Results / $22.50 Price

Again, little has changed when revenue per acre increased from $17.39 to $22.50. For both GM and GE seed development projects, the time and cost of each phase has the largest impact on the decision to continue or abandon the project.

5.3.2. Discount Rate

In the base case, it was assumed that the discount rate was 15%. If organizations required a higher return of 18%, all else equal, the MRA increases for both GM and GE seed projects to 10,288,116 acres and 1,156,579 acres respectfully. A 3% increase in the discount rate increased the MRA for GM and GE seed projects by 47% and 34% respectfully. Figure 5.7 and 5.8 shows the regression coefficients of stochastic variables for GM and GE seed projects when the base case discount rate is increased to 18%.

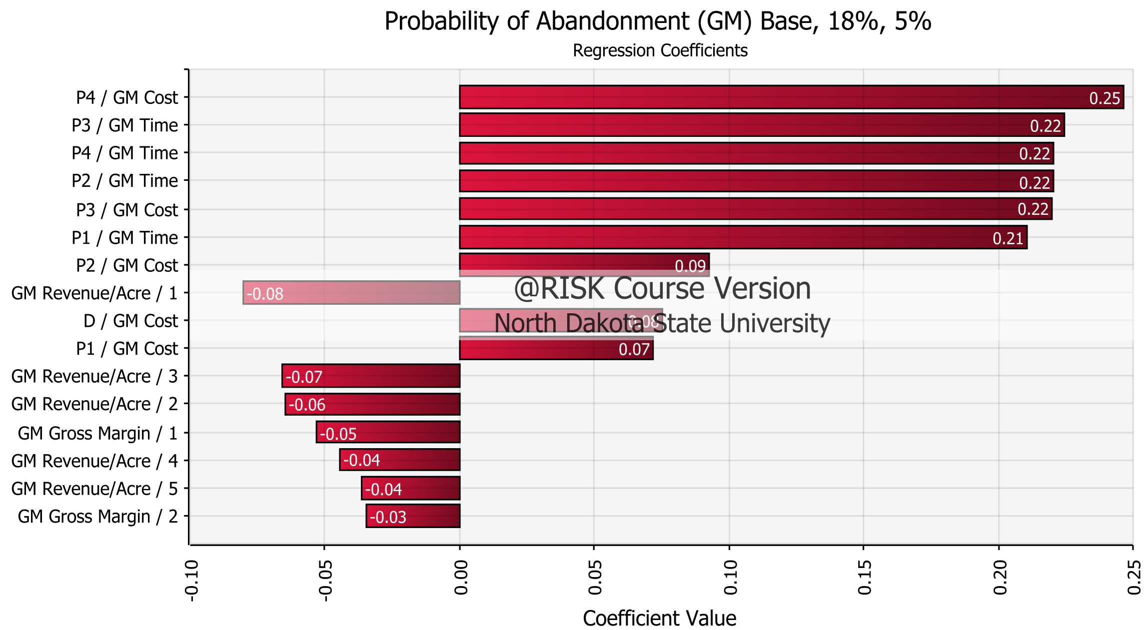

Figure 5.7. GM Results / 18% Discount Rate

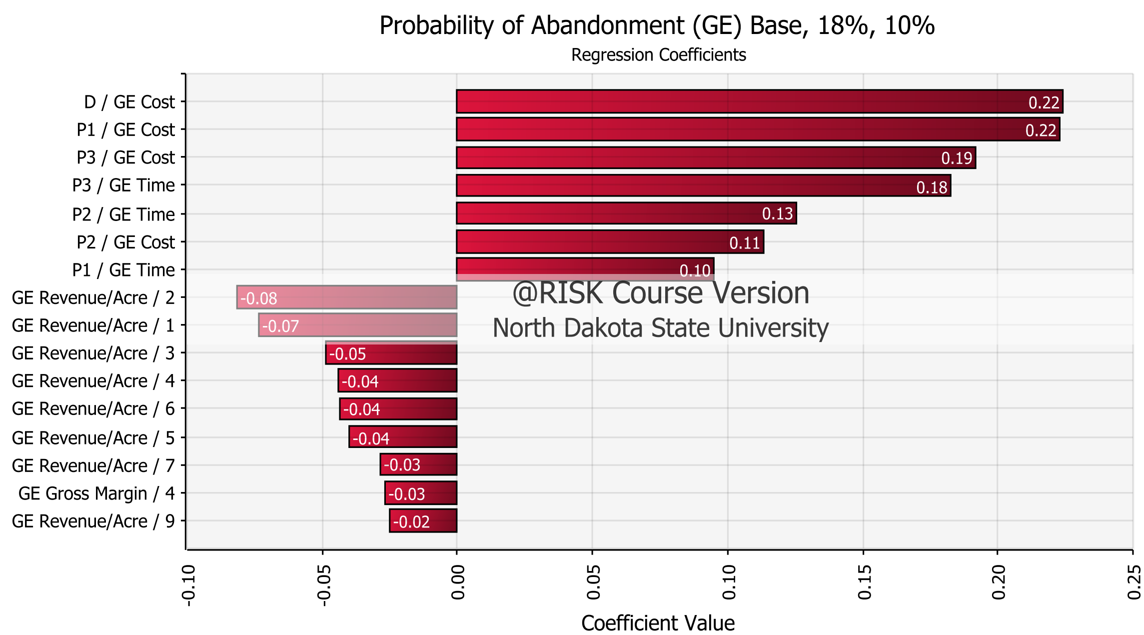

Figure 5.8. GE Results / 18% Discount Rate

The regression coefficients of the base case versus the base case with an 18% discount rate are nearly identical. GM seed projects are the most sensitive to the time each phase takes to complete compared to GE seed projects which are most sensitive to the cost of each phase.

5.3.3. Confidence Intervals

In the base case, it was assumed that the probability of abandonment was 5%. If organizations required a lower probability of abandonment (a higher degree of certainty) of 1% all else equal, the MRA increases for both GM and GE seed projects to 8,274,191 acres and 957,482 acres respectfully. By increasing the probability of success from 95% to 99% the MRA for GM and GE seed projects increased by 18% and 12% respectfully. Figure 5.9 and 5.10 shows the regression coefficients of stochastic variables for GM and GE seed projects when the base case probability of abandonment is changed from 5% to 1%.

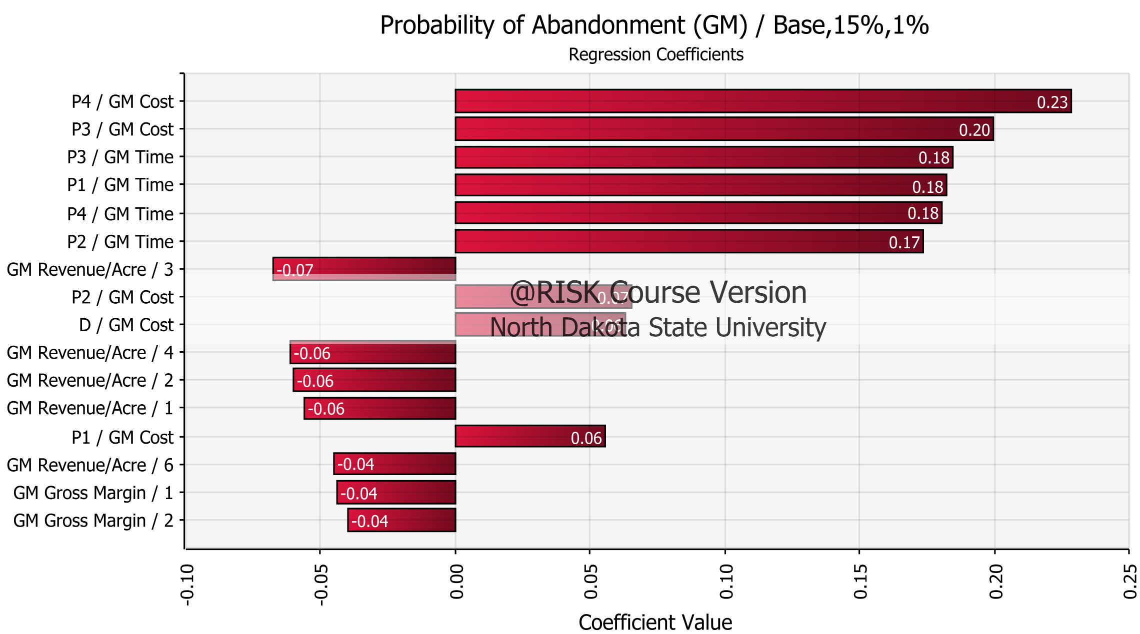

Figure 5.9. GM Results / 99% Confidence Interval

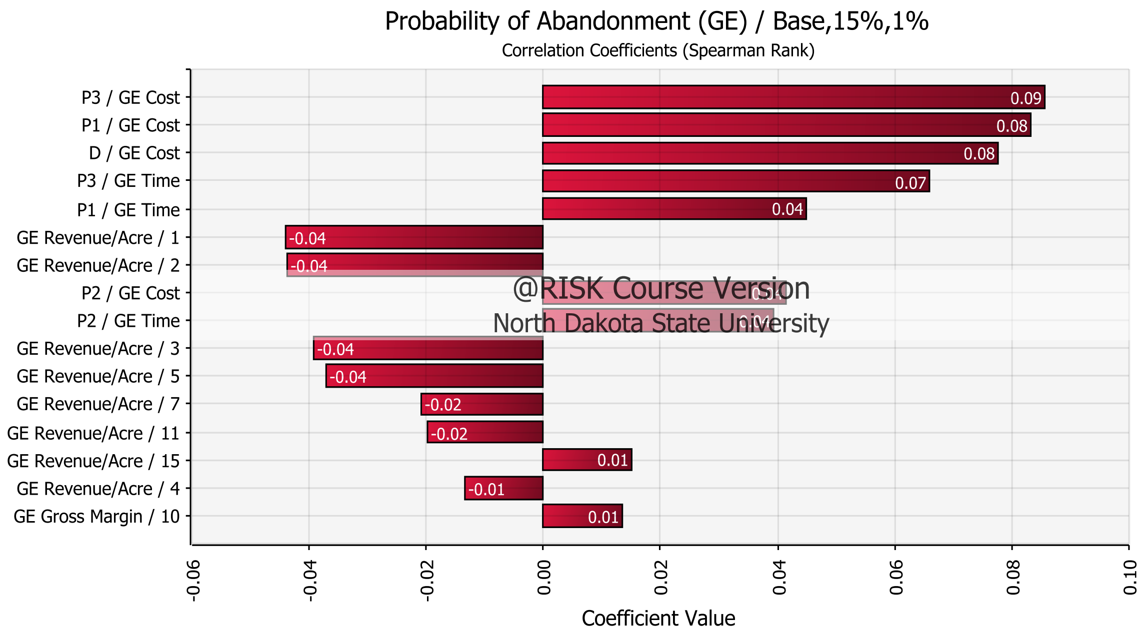

Figure 5.10. GE Results / 99% Confidence Interval

The regression coefficients of the base case versus the base case with an 99% probability of success are again very similar. GM seed projects are the most sensitive to the time each phase takes to complete compared to GE seed projects which are most sensitive to the cost of each phase. However, when the probability of success increases from 95% to 99%, revenue per acre becomes far more important.

5.4. Summary

To better understand the economics of GM and GE seed development, a real option model was created to simulate an environment a seed developer may face selling into the North Dakota seed market. Developers have a choice at the end of each developmental phase to either continue with the project or abandon it. To understand the MRA for potential GM and GE seed projects, the probability of abandonment was fixed at 5% and the model was optimized using Risk Optimized in @Risk.

The base case scenario represents the environment a seed developer may face selling into the North Dakota wheat seed market. A seed developer, developing a GM or GE wheat product could reasonably expect $17.39 revenue per acre, 15% return on the project, a 3% risk-free rate, and a 95% probability of success in the North Dakota market. Other underlying variables such as time and cost of each developmental phase were set utilizing a risk-triangle distribution methodology reflecting all ten survey responses.

Sensitivity analysis was conducted to demonstrate the impact on the MRA by changes in revenue per acre, discount rate, and probability of success. Revenue per acre, discount rate, and probability of success were chosen as the variables included in the sensitivity analysis because they are variables that can be controlled. Price of the product, required return, and probability of success are all parameters chosen by a management. The MRA can also be thought as a risk management tool. When a management decides to undertake riskier behavior (lowering price or increasing expected return) the MRA will penalize the decision by increasing the market share required to allow that price and allow that return. To justify any price or return input, an organization must capture the market share described by the MRA.

Additionally, the probability of success is a direct input in the MRA model. Risk adverse firms require high probabilities of success to invest in a project while risk loving firms may accept lower probabilities of success. The MRA model demonstrated that the MRA and probability of success are directly related. As probability of success increases, MRA increases. As probability of success decreases, MRA decreases.

CHAPTER 6. CONCLUSION

6.1. Introduction

Seed developers face many risks when developing a new crop variety. Seed developers also have many technologies at their disposal to create a new crop variety. Genetic modification and genetic editing are two technologies being used today by seed developers. With the overall goal of creating a profitable project, seed developers must choose carefully which technology to use and understand the underlying risks of both.

6.2. Problem Statement

Organizations that develop different crop seed theoretically have an endless number of projects they could do. If an organization wishes to develop a new wheat seed for example, using either GM or GE technologies, how should they decided which projects to invest in? It's not clear if they should develop the new wheat seed using GM or GE technologies. The fundamental question that needs to be answered is: if a seed is developed using a GM or GE technology, how much market share must be captured to make the project profitable? Minimum required acreage (MRA) can compare GM and GE technologies on a apples-to-apples basis. It is a risk control tool that provides a reality check to seed developers and gives them the ability to tease out which projects are promising and which projects they should ignore.

6.3. Genetic Modification and Genetic Editing Technologies

Tools such as CRISPER or TALEN are relatively new, so new that few companies have commercialized a genetically edited crop. Genetically modified crops have been shown to have positive impacts on agronomics and farm economics and are planted on millions of acres every year.

Genetic editing promises to drag down the cost and speed up the developmental of new crop varieties. There is big money at stake and many paths can be taken to develop new crop varieties. Given genetic modification and genetic editing are the leading technologies today, this study compares the technologies and presents a risk framework that can help seed developers choose a path.

6.4. Real Option Pricing Methodology

Most capital investments have some degree of risk and uncertainty. Because most capital investments are done in stages, managers are able to survey the business environment every time period and adjust their capital investment strategies accordingly. The uncertainty of future business environments and investment timing are qualitative variables in the investment process. Uncertainty is a variable that effects future cash flows of an investment, dramatic increases or decreases in future earnings has major effects on the return on investment.

Real options analysis is a methodology that can be used to estimate an investments value by accounting for investment flexibility and uncertainty. ROA, NPV, and DCF methodologies are all viable valuation techniques (Turvey 2001), each of which has its benefits and drawbacks. Real option analysis on the other hand does capture management flexibility and dynamic investment strategies. As uncertainty increases in an investment, the difference in valuations between NPV and ROA increases because NPV techniques are unable to account for volatility (Alizadah and Nomikos 2009). When there is high uncertainly in the future and cash flows cannot be accurately predicted the investment should be valued with ROA, not NPV techniques which do not account for uncertainty, management flexibility, and dynamic strategies (Turvey 2001).

6.5. Empirical Model

Chapter 4 presents the empirical model for determining the minimum required acreage (MRA) for both GM and GE seed projects. The foundation of the MRA model is a real option, specifically the option to abandon. Similar to the financial put option, if the value of the project falls below its salvage value, the owner of the option has the ability to exercise the option and abandon the project.

Every seed developer has the right, but not the obligation, to abandon any seed project. After each developmental phase, seed developers can evaluate the environment and continue the project or abandon it, freeing capacity for a potentially profitable project. The ability to abandon a project and start a new one after every developmental phase provides flexibility to any seed developer. This flexibility provides value to the seed developer in three ways. One, the seed developer has the ability to abandon projects with major time and cost overruns. Second, the seed developer has the ability to start a new project that could be profitable. Third, in the process of developing a new seed, new research and developmental methodologies or processes are discovered that can then be applied to all upcoming projects.

The MRA model is comprised of two smaller models. Model one is a net present value (NPV) model and model two is a stochastic binomial option pricing tree. Model one's function is to calculate the mean present value of expected cash flows from both GM and GE seed projects. Model two is a stochastic binomial option pricing tree which incorporates the value of the flexibility discussed above after every developmental phase. When the real option value falls below the projects salvage value, the seed developer should exercise the option and abandon the project.

In any given iteration of the simulation, the probability the seed developer should exercise the option and abandon the project is calculated. Therefore, the probability of exercising the option can be fixed and then the model can be optimized to solve for what value a specific underlying variable would have to be to satisfy the fixed probability of exercising the option to abandon the project. In the study, the probability was fixed, and acres planted was the variable optimized to determine the MRA needed to make the probability of exercising the option equal to the fixed probability, subject to all other stochastic variables in models one and two.

6.6. Results

The MRA model simulates the environment a seed developer selling into the North Dakota wheat seed market may encounter. Monte Carlo simulations were implemented in both model one and two using @Risk to simulate 10,000 iterations. Risk Optimizer was implemented in model two, the stochastic binomial option pricing tree. There are ten stochastic variables and three management variables in both the GM and GE seed models. Management variables are defined as the variable's management would have direct discretion over from a corporate finance perspective. The management variables are average price per acre, required rate of return, and probability of abandonment percentage. The ten stochastic variables are time and cost of five developmental phases and the gross margin for both GM and GE seed development processes.

A base case and sensitivity analysis were conducted. Base case assumptions were revenue received was $17.39 per acre, 15% required rate of return, and a 5% probability the project will be abandoned. Sensitivity analysis was conducted to determine the main drivers of the MRA. Sensitivity analysis varied the three management variables revenue per acre $17.39-$22.50), required rate of return (12%-18%), and probability of abandonment (1%-10%).

6.6.1. Conclusions from Base Case

The base case assumes $17.39 revenue per acre, 15% required rate of return, and a 5% probability the project will be abandoned. The ten underlying stochastic variables had a mean value resulting from surveys submitted and a risk-triangle distribution.

A seed company developing a GM seed would need its product planted in 7,016,223 acres for fifteen years to give the project a 95% probability of being profitable. Developing a GE seed, a company would need its product planted in just 857,633 acres for fifteen years to give the project a 95% probability of being profitable. A GE seed needs 8.11 times less acreage to be profitable relative to a GM counterpart.

6.6.2. Conclusions from Sensitivity Analysis

As discussed above, the sensitivity analysis was designed to measure the different MRAs needed as a company's management changes its seed price, required return, or probability of abandonment. Management would change those three variables depending on how risk loving or risk adverse they are. If a management is risk loving, they may only require a 12% return with and accept a 10% probability that some project will be abandoned. A risk adverse management might require an 18% return and a 1% probability that the project will be abandoned.

In the case of a risk loving management, the MRA varies between 4,324,696 – 5,570,485 acres for GM projects and 539,560 – 700,678 acres for GE projects depending revenue per acre. GE projects need 8 times less acreage to be profitable relative to GM projects under the same conditions.

In the case of a risk adverse management, the MRA varies between 7,205,694 – 9,368,572 acres of GM projects and 749,608 – 1,080,669 acres for GE projects depending on revenue per acre. Here, GE projects need nearly 9 times less acreage to be profitable relative to GM projects under the same conditions.

6.7. Implications of Results

The implications of the results from chapter 5 are very different depending if you're a seed developer or a farmer planting the seed.

6.7.1. Implications for Seed Developers

There are three main implications that can be drawn from the results of this study. One, the success or failure of a project is almost entirely dependent how good the organization is at keeping the project on time and on budget. Two, the GM and GE regression coefficients seem similar, but suggest that GE technology can be greatly improved from an investment standpoint while GM technology is as efficient as it can be. Third, the MRA is very dependent on the risk aversion level of the organization.

Operation excellence is a large factor driving the probability of abandonment up or down. In the base case, the most impactful variables driving the MRA was the time and cost of each developmental phase for both GM and GE projects. Of the sixteen most impactful drivers of MRA in the GM project, nine were either time or cost of a phase, with the nine having nearly four times the impact than the other seven drivers. Of the sixteen most impactful drivers of MRA in the GE project, seven were either time or cost of a phase, with the seven having nearly three and a half times the impact than the other nine drivers. It is clear that in both the GM and GE base case, operational excellence is a very important driver of project profitability in the future.

In the base case, both GM and GE project's regression coefficients (Figure 5.1 and 5.2) seem similar but are actually very different. Of the top six most impactful variables for a GM project, four were time based. Contrast that with the GE project, four of the top six most impactful variables were cost. The issue, time is dependent on biological processes such as greenhouse and field trials or agronomic evaluation and seed bulk-up. One cannot really increase the speed of these biological processes. On the other hand, costs are function of underlying developmental processes. Technology or developmental methodologies can be improved, thus potentially driving costs down. One could assume all costs can be driven down as technology and methodologies are improved, implying the top variables that impact the MRA would all be time related.

Currently, four of the top six variables with the largest impact on MRA in the GM project are time related, suggesting there is little technological or methodological improvement will do to improve the economics of GM projects. For GE projects, four of the top six variables with the largest impact on the MRA are cost related, suggesting that GE project economics will benefit greatly from technological and methodological improvements.

The last important implication for seed developers is that the overall level of risk aversion is a large determinant of the MRA for GM and GE projects. Because probability of success is an input, organizations can input their preferred probability for success into the model. Generally, a risk adverse organization will require a high degree of certainty, 95% probability of success, before investing in a project. A risk loving organization may require less than a 95% probability of success before investing in a project. For GM projects, the MRA varies greatly depending on the level of risk aversion the seed developer has. For example, a risk loving seed developer may undergo a GM project if they believe they can penetrate the market and get their seed planted on 4.9 million acres. A risk adverse seed developer may wait to undergo a GM project until they believe they can get their seed planted in 8.3 million acres, a 69% increase in MRA.

For GE projects, there is a similar difference between risk loving and rick adverse attitudes and the MRA. A risk loving seed developer may be willing to engage in a GE project if they can capture 0.62 million acres of the market. A risk adverse seed developer may wait to develop a GE seed until they could capture 0.92 million acres of the market, a 48% increase in MRA.

Seed developers need to be very aware of their operation efficiency, understand that GM processes have less slack to ring out of the process relative to GM projects, and their overall level of risk aversion plays a large role in determining a proper MRA of GM and GE projects. If seed developers do not keep a close eye on the three points above, it is very easy to lose track and enter into an unprofitable project.

6.7.2. Implications for Seed Demanders (Farmers)

There are two major implications for farmers when it comes to GM vs. GE seed. One, the MRA suggests that GE could potentially leaded to ultra-specific seed varieties that are optimized for an individual farmer's soil and climate. Two, because GE seed have such a lower MRA relative to GM seeds, it is possible GE seeds lead to a subscription model of buying seed.

On average, the MRA for GM seed projects is eight times larger than the MRA for GE seed projects. This reality is interesting because it implies that for every individual GM seed variety on the market, eight different GE seed varieties could replace it. This opens up the possibility that GE seed varieties can be engineered for specific farmers depending on their soil composition and climate.

Because of the implication above, the differences in MRA between GM and GE seed projects could also change the business model for seed developers and seed buyers (farmers). The seed developer could enter into an agreement with a farmer in which the seed developer would make seed specifically for the farmer, optimizing the seed against the environment the farmer faces. It's possible that the business model could turn into a subscription model where the farmer subscribes to the seed developer and buys and sells seed exclusively with the seed developer. This model could decrease the risk to farmers and increase the financial stability of many seed developers, which could lead to important scientific and technological breakthroughs in seed development.

6.8. Summary

The primary objective of this study was developing a methodology that would allow for the comparison of GM and GE seed developmental technologies. The concept of minimum required acreage (MRA) was created and was used to compare GM and GE processes by determining how many acres (market share) would need to be captured, all else equal, to make both GM and GE projects profitable within a 95% probability. It was shown that, on average, an organization developing a GM seed would have to capture eight times more market share over a GE seed to have a realistic chance of being a profitable project.

6.8.1. Contribution to Literature

No known work has been done to explicitly compare GM and GE seed developmental techniques as to understand the resulting economics of the seed. The development of a GM and or GE seed involve many variables. Prior, it was not clear which variables were the most impactful to the profitability of either project. This study has begun to explain the similarities and differences in GM and GE seed development and has created a starting point for future research of understanding the similarities and differences of the two different approaches in developing seeds.

6.8.2. Limitations

This study has many limitations. The data and distributions used can be best described as educated guesses. The results from the surveys and interviews with expects resulted in data with a very high variance. It is not clear if all organizations surveyed have very different costs and phase lengths to their competitors or it could be that many firms do not have a clear understanding what the time and cost of each developmental phase actually is. It's possible both the time and cost of each phase is hard to pin down and they provided their best guess. It's also possible they misunderstood what was asked and they provided data that was true but described different processes.

Regulation is also a serious limitation. Foods created with GM seed is very highly regulated in the United States and around the world. GE seed is a relatively new concept and there is high uncertainty what regulation on GE seed will look like a decade from now. It's possible that regulations increase both the time and cost of development for GE seeds resulting in a narrowing of the difference in MRA between GM and GE seed. This study assumed GM seed was heavily regulated, from both time and cost perspective. Regulations of GE seed was assumed to be relatively mild with respect to both time and cost.

Lastly, the study was done by a person with a background in economics, not biology or genetics. It must be understood that the author of this study is highly ignorant with respect to the biology of wheat and its genetics. The author is also highly ignorant in gene altering technologies such as CRISPER, TALEN, and zinc finger. It's possible that a high degree of ignorance in those three areas could create unrealistic expectations of GM and GE seeds, their costs, and the time and processes it takes to actually develop them.

6.8.3. Further Research

Using the framework created in this study, there are three obvious paths for the future study comparing GM and GE developed seed.

Gathering and analyzing the correct data is vitally important to the comparison of GM and GE seed. Theoretically, every year that passes implies there should be more and better data on both processes. Further research on this topic must include a legally binding non-disclosure agreement (NDA) between the researcher and the seed developers. An NDA would allow the researcher a clearer view of seed developers research and development process.

Regulation must be research further. How regulation effects GM seeds is relatively well known. However, the laws regulating GE seed are still being worked out all around the world. It is unclear how regulated GE seed will be, what it will cost, and how long that regulation process takes. Chapter 5 shows very clearly that the last phases of development, where regulations are accounted for, have a large impact on the MRA.

Lastly, this study makes strong scientific assumptions regarding an organizations ability to even create a GM or GE seed. To relax this assumption and create a model that is more closely aligned with reality, it could be beneficial for a researcher deeply knowledgeable in the biology and genetics of crops and tools such as CRISPER and TALEN. Collaboration between economists and biologist/geneticists will undoubtedly move the research of understanding the similarities and difference of GM and GE crop seed forward.

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