VALUING AND PRICING OF RANDOM & NON-PERSISTENT GENETICALLY MODIFIED TRAITS (Corn & HRSW)

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Title

VALUING AND PRICING OF RANDOM GENETICALLY

MODIFIED TRAITS USING REAL OPTIONS

By

SUMADHUR SHAKYA

The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

ABSTRACT

Shakya, Sumadhur, M.S., Department of Agribusiness and Applied Economics, College of Agriculture, Food Systems, and Natural Resources, North Dakota State University, August 2009. Valuing and Pricing of Random & Non-Persistent Genetically Modified Traits (Corn & HRSW). Major Professor: Dr. William W. Wilson.

With many genetic traits discovered and many more in progress, it is imperative to the industry that firms (biotechnology companies) decide on the trait valuation and pricing. This includes more than one trait (also referred to as stacked traits) in a single variety of crop; the risk and uncertainty of expected returns associated with the development and release of a variety increases even more in case of stacked traits.

The purpose of this thesis is to develop a model that can be used for the valuing and pricing of genetically modified (GM) traits that are random, sporadic, and non-persistent (e.g. drought tolerance, heat/cold stress) using the real option approach. The efficiency gain in case of occurrence of random event and expression of GM traits will be measured and used as a decision factor in determining the value of GM trait(s) at different phases of development.

Risk premiums representing the value of GM trait to growers is calculated across risk averse attitudes. The return to labor and management (RTLM) provided by a GM trait is used to calculate the risk premiums when variation in parameters is allowed to be same as that reflected in historical data and gains from GM traits are realized. Monte Carlo simulation and stochastic efficiency with respect to a function (SERF) are used to estimate the certainty equivalents that decision makers would place on a risky alternative relative to a no risk investment. Certainty equivalents are estimated across a range of risk aversion coefficients and used to rank alternatives and determine where preferences among alternatives change while estimating risk premium for the base case (no trait), drought tolerance, cold tolerance, NUE, and All traits (all traits combined into one as a stacked trait). Premiums provide perspective on the magnitude of differences in relative preferences among choices. The range of ARAC utilized was from 0.00 to 0.15 for all three crops. The risk premiums are treated as a potential source of revenue in the model as a technology fee charged by a biotech company.

This thesis uses the Real Option methodology to evaluate GM traits as Option values at various stages of development. This approach helps managers decide the best possible option in making a certain decision today. It is also helpful in comparing different pathways (series of decisions) and thus better exploits the potential cash return in the future from investments made today (Figure D.1, Figure D.2). Three possible options to "continue", "wait", and "abandon" were modeled in this thesis. Such modeling determines the possible option values of GM traits at different stages of development depending on the kind of choices made at different points of time.

This thesis shows that various GM traits that are out-of-money (OTM) at initial stages have increased probability of being in-the-money (ITM) at later stages of development. Sensitivities show that a share of potential technology fees and acreage of GM crops play a significant role in option values being ITM.

Stacked traits provide a better chance of being ITM, thus the option to continue will be exercised by management. The option to wait causes reduction in option value. Among individual traits, drought tolerance has the greatest maximum option value in most cases. Therefore, if management has to choose the development of only one GM trait, it is most likely to choose to invest in the development of drought tolerance.

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INTRODUCTION AND PROBLEM STATEMENT

Introduction

Genetic engineering and modifications in plants, animals, and microorganisms has been one of the most significant breakthroughs for the agriculture industry despite the resistance by policy makers across the world attributed to various reasons. After a decade of availability of genetically modified (GM) crops to US farmers, adoption of GM crops in the United States has led to ease in farming practices, reduction in chemical application, and increase in output. Improved seed technology has contributed to a more than 50 % increase in agricultural productivity in developing countries. Improved seed varieties help in reducing input costs to the farmers or result in increased output.

According to a non-profit corporation *"In 2010, Monsanto and Dow AgroSciences hope to introduce SmartStax, an eight-trait Corn stack – three genes for above-ground insects, three for below ground, and tolerance to Liberty and Roundup herbicides. A little further down the road is a drought-tolerant Corn that was standing tall and looking good under a translucent tent that kept rainfall away."* (Growers for Biotechnology, 2008).

General Problem Statement

With many genetic traits discovered and many more in progress, it is imperative for the industry that firms (biotechnology companies) determine the value and price of these traits. Global area under biotech crops is shown in Figure 1.1.With emphasis on stacked traits, which include more than one trait in a single variety of crop, the risk and uncertainty of expected returns associated with the development and release of a variety increases even more. The value of the trait essentially depends on the 'efficiency gain' –the relative gain to adopters in case of event occurrence. Although literature suggests that efficiency gain is only partial, GM traits that have been commercialized in the past are relatively persistent and nonrandom in the value they provide to users, primary growers. These include, as examples, herbicide tolerant (HT) and insect resistant traits. Some of the future traits that are under development and are anticipated to be commercialized, however, are in response to more sporadic (or random) conditions. These include, as example, drought tolerance (one of the stress traits being pursued by numerous companies and organizations) in corn and wheat (numerous US land grant colleges, Victoria government, etc). In the case of Canola, shattering is random, but again its value is sporadic and will be in response to random conditions. Moreover, valuing the price of GM traits becomes difficult as their economic value can be determined only if there is an event occurrence for the expression of random traits.

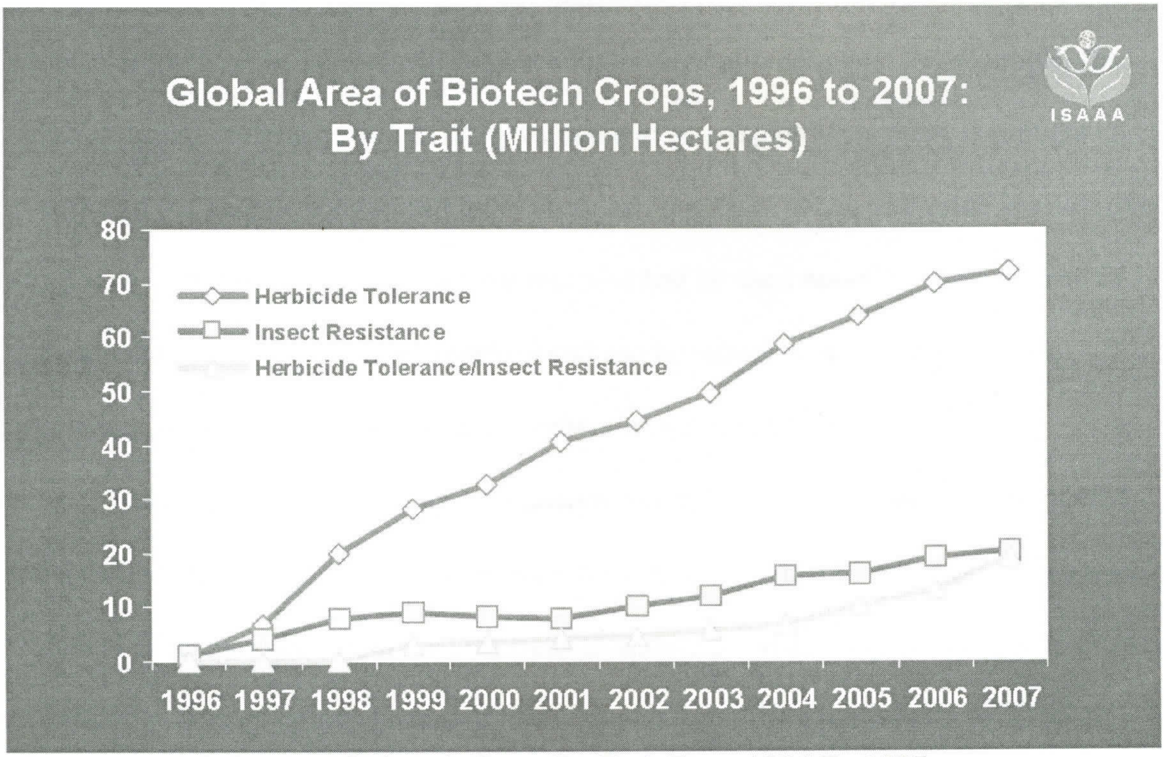


Figure 1.1. Global Area Of Biotech Crops By Trait From 1996 To 2007
Source: Clive James, 2007, ISAAA Brief 37-2007.

Since the event occurrence has equal possibility of happening or not happening, but it can be deduced, the pricing of a variety with a GM trait has to be such that the adopters are ready to pay, even when they are uncertain about its utility. In case of event occurrence, its economic value can be realized. After occurrence of an event, there is a second level of uncertainty as to whether the trait is useful. The usefulness of GM trait refers to the technical efficiency gained in the crop. It is only when both of these events occur that the true value of inclusion of random traits, can be arrived at. The efficiency gain in case of drought tolerance on wheat has been reported up to 20 % in field trials in Australia. Although the incidence of drought is in itself random, the trait essentially provides a better chance of higher yields in case the drought occurs. Whereas the non occurrence leads to a situation of uncertainty in terms of extent of economic value. It also results in no value to adopter. Both these situations will impact adopters and non-adopters. For example, the value of drought tolerance will be truly valuable to an adopter when there is drought (first event), and the genetic trait(s) trait expresses itself (second event), and value is given over and above what the adopter would have received had he used non-GM variety. Each of these events has an individual probability and can be valued as a real option model, accounting for different phases of development of trait(s) in GM wheat or corn.

The objective of this thesis is to analyze prospective valuing and pricing of GM traits (primarily drought and cold tolerance in HRSW and corn) by measuring the possible technical efficiency gain from the GM traits to adopters and arriving at its value to growers and industry during various phases of development (over the a period of 8 to 10 years, including commercial release) using real option model approach. The model builds on that used by Huso and Wilson (2006), Flagg and Wilson (2008), and Berwald, Carter, and

Loyns (2008). Stochastic simulation is used to account for randomness in variables representing uncertain outcomes associated with development of GM trait(s) including uncertainty and cost associated with their commercial release.

Apart from research and development costs and the time that it takes to develop a variety, the regulatory policies and general perception among end and non-end users plays a significant role in deciding the benefit of the GM crop. This in-turn affects the overall the cost benefit aspect of any one or more GM trait included in the crop.

Specific Problem Statement

The purpose of this thesis is to develop model that can be used for valuing and pricing of GM traits that are random, sporadic, and non-persistent (e.g. drought tolerance, heat/cold stress) using the real option's approach. The efficiency gain in case of occurrence of a random event and GM traits expressed will be measured and used as a decision factor in determining the value of GM trait(s) at different phases of development.

The value of a GM trait also depends on growers risk averseness of growers. Highly risk averse growers are expected to be early adopters of GM technology. Such growers will have higher perceived value for GM trait. This perceived value of a GM trait by growers can be treated as potential technology fees for biotechnology firm. The technology firm gets majority of its revenue from technology fees. Other sources of revenue can be licensing of the GM trait to other firms. There may also be some leakage to firms (unlicensed use of GM trait). Drought and cold tolerance, Nitrogen Use Efficiency (NUE) as individual traits and combination of all these ("All") in corn and hard red spring wheat (HRSW)) are some of the traits treated as random in this paper. The uncertainty in development of GM traits during various phases constitutes the primary element of the problem.

Sometimes GM crop plants perform better than its wild type counterpart in drought conditions, but may yield less in normal conditions. This is an important factor and thus the potential GM traits tested at International Rice Research Institute (IRRI) are being designed to be activated by drought (efficiency gain by drought resistant gene is realized when drought occurs) so as to avoid any yield penalty in normal conditions (Reyes and Lanie, 2009).

Since too many traits are under development by various firms in individual and stacked traits with significant high costs associated, it becomes imperative for decision makers to know the risk associated with developing the trait and the possible options at various stages of development in future. Uncertainty associated with event occurrence is a primary factor in the value of GM trait. In addition this uncertainty in regulatory procedures and in obtaining permission for commercial release is another significant factor affecting the value of GM traits. The value of a trait is realized in case of event occurring. For example in case of drought tolerance, the value of trait can be realized by farmer only if drought occurs. By how much the GM crop (with drought tolerance trait) performs better relative to crops (GM or non GM) without the drought tolerance trait is another matter of interest, which is called 'efficiency gain'. The value of traits in development and decisions to go ahead, have traditionally been based on net present value (NPV). However this method significantly fails to capture the risks associated at various phases of development and also the fact that management has the option of abandoning or continuing with the development of the trait thereby, continuous discounting of future cash returns does not gives a clear picture.

Background

The global status of commercialized GM crops in 2007 has been encouraging. Planting of GM crops by farmers has consistently increased on aggregate basis in last twelve years since 1996 to 2007 due to the significant and consistent benefits to an extent of 114.3 million hectares (282.4 million acres) with 12% (second highest in past five years) increase in last year alone, which is 12.3 million hectares (30 million acres).

GM crops have significantly contributed to economic and ecological improvements to farmers in both developed and developing countries. Millions of poor farmers have been benefited from social and humanitarian benefits and contributed to the alleviation of their poverty. Farmers are swiftly adopting varieties that have more than one GM trait referred as "stacked traits", which combine multiple benefits in a single GM variety. Adoption growth can be better explained in terms of "trait hectares", something similar to "passenger miles" in air travel (ISAAA, Brief 37-2007). The "trait hectares" have increased at 22 %, to reach 143.7 million hectares. Recently China has reported to have planted 250,000 GM poplar trees with a view of reforestation by insect-resistant trees.

By 2007, 11 developed and 12 developing countries have planted GM crops, with eight of them growing more than 1 million hectares, across different continents. Poland, an EU country, adopted the GM maize crop for the first time. Total acreage from 1996 to 2007, is 690 million hectares (1.7 billion acres). This fast adoption rate results from significant and consistent performance of GM crops benefitting both marginal and large farmers not only economically but also in terms of other social and environmental benefits. Interestingly, the number of farmers who adopted the GM crops during 2007 exceeded 50 million across 23 countries (Figure 1.2). The growth rate in developing countries (26%) is thrice than that of developed countries (6%). In 2007, although the United States, Argentina, Brazil, Canada, India, and China continued to be the major adopters of GM crops worldwide, the share of United States continues to have a declining share of the global area due to a increasing global adoption (Figure 1.3, ISAAA, Brief 37-2007)

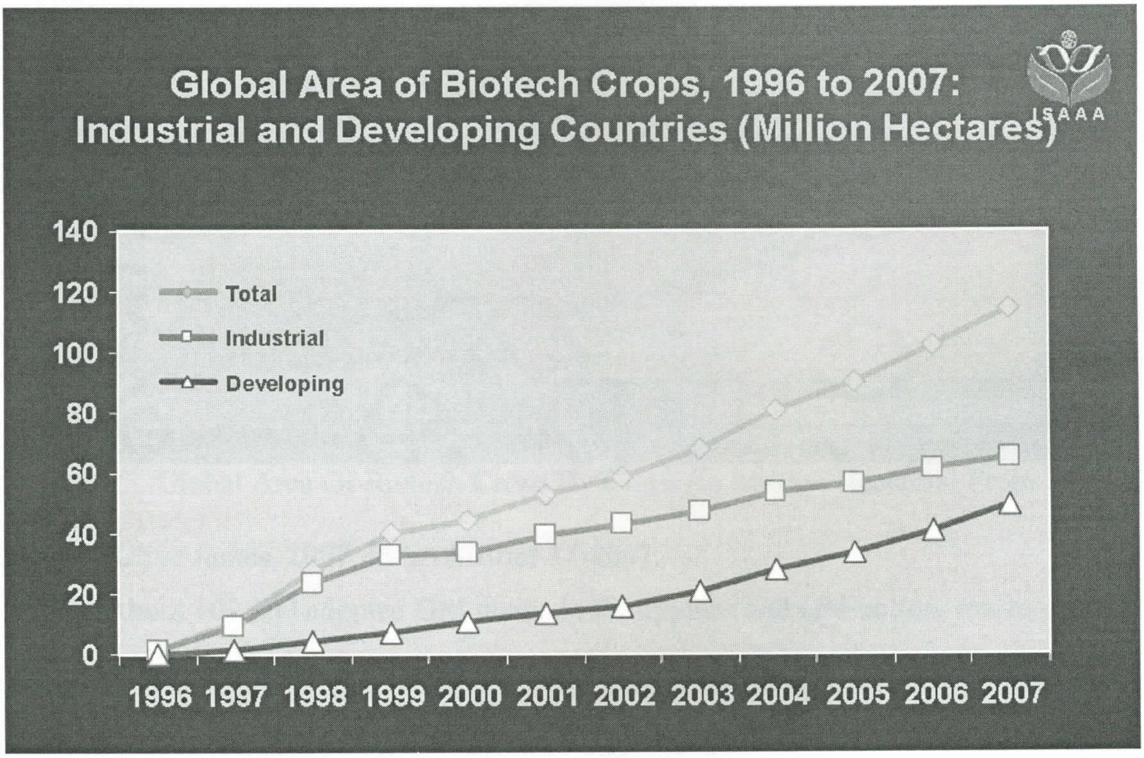


Figure 1.2. Global Area Of Biotech Crops In Industrial And Developing Countries From 1996 To 2007 (In Million Hectares).

Source: Clive James, 2007, ISAAA Brief 37-2007.

Over 10 million (approximately 11 million) small and marginal farmers benefitted in developing countries, which is 90% (9.3 million in 2006) of the total 12 million farmers worldwide, the rest of 1 million being from progressed nations like USA and Canada. Most of the 11 million have adopted Bt cotton with 7.1 million in China, 3.8 million in India.

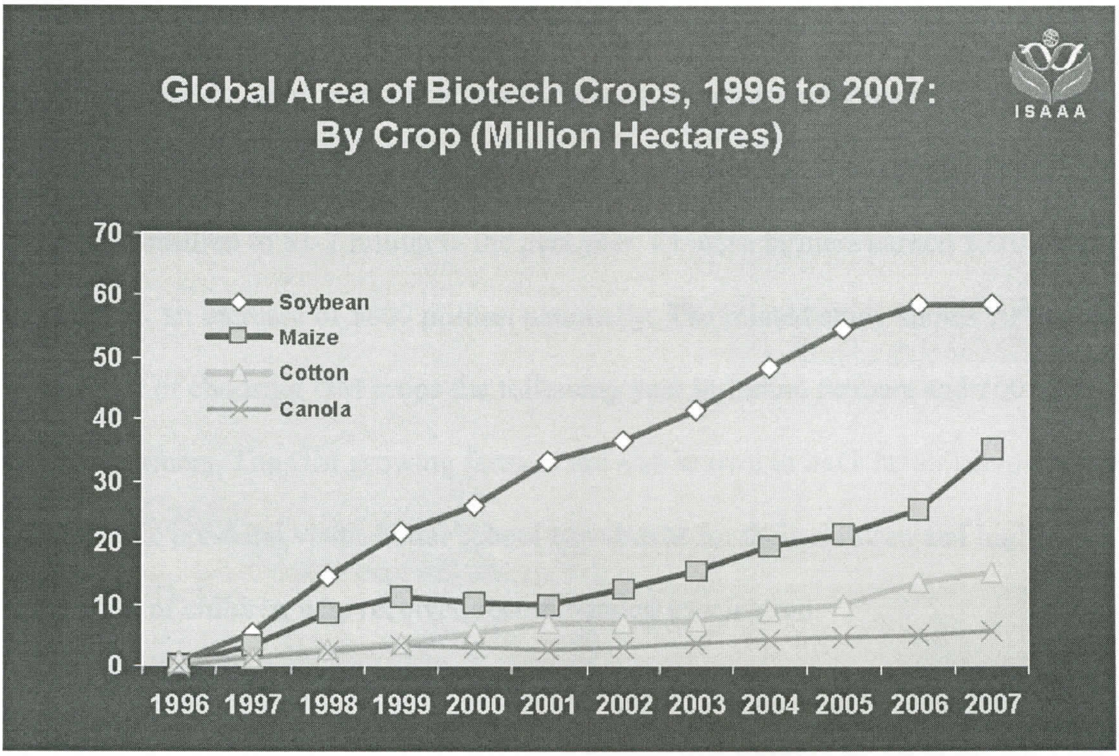


Figure.1.3. Global Area Of Biotech Crops By Crops (In Million Hectares) From 1996 To 2007.
Source: Clive James, 2007, ISAAA Brief 37-2007.

About 100,000 adopted GM maize in Philippines and GM cotton, maize, and soybeans in South Africa, including women farmers. This is modest but significant contribution by increased number of small farmer incomes towards United Nation's Millennium Development Goals, aiming at reducing poverty by half by 2015. This has even more huge potential in next half of the decade of commercialization till 2015 especially in countries like India, China, and South Africa.

Clive James, chairman & founder of the International Service for the Acquisition of Agri-biotech Applications (ISAAA), has said (ISAAA Brief No. 37-200) that with increase in food prices all over the world, GM crops have gained significance in today's context. The GM crop adopting farmers are at a socio-economic advantage relative to non-adopters.

There has been an increase in yields of Bt cotton in India and China by 50 % and 10 % respectively along with reduction in chemical application by over 50 % or more. Indian farmers earned \$250 or more per hectare thereby increasing national famer income from \$840 million to \$1-7 billion in the past year. Chinese farmers earned \$220 on average per hectare, an increase of \$800 million nationally. The related study shows 90 % confidence of choosing GM crops the following year in Indian farmers and 100 % in Chinese farmers. The GM growing farmers are also known to have better socio-economic benefits like pre-natal visits, better school enrollment for their children and higher proportion of children who received recommended vaccination.

All these benefits make GM crop technology an important tool in achieving Millennium Development Goals of reducing hunger and poverty by 50 % by 2015 and in ensuring a more sustainable growth in agriculture, specially, with growing demand to meet not only for food, but also for feed fiber and fuels (including bio-fuels).

Current Global Scenario

According to Feedstuffs (2008): "*World grain prices have been rocketed recently due to drought and other weather related concerns. Drought tolerant crops look to be one of the most promising upcoming biotech traits in pipeline, providing ability to produce "more crop per drop" of water.*" (Fatka, 2008). It also said, "*BASF SE, the world's largest chemical maker, said drought tolerant seeds it is developing with Monsanto Co. will reach farmers in 2012 for planting next year.*"

With significant economic and socio-environmental benefits, accompanied by over 12 years of knowledge and experience, GM crops are expected to grow even more so in near future, specially, in developing countries which have greatest need and potential for GM crops (ISAAA, Brief 37-2007). Countries like Australia are in process of field-testing drought tolerant wheat and two of the states have lifted the four year put on GM canola. India is fast recognizing the positive impact of use of GM crops in feeding its billion populations by making itself self-sufficient in food grain and oil seeds. An approval for first ever GM food crop and a GM eggplant is shortly expected.

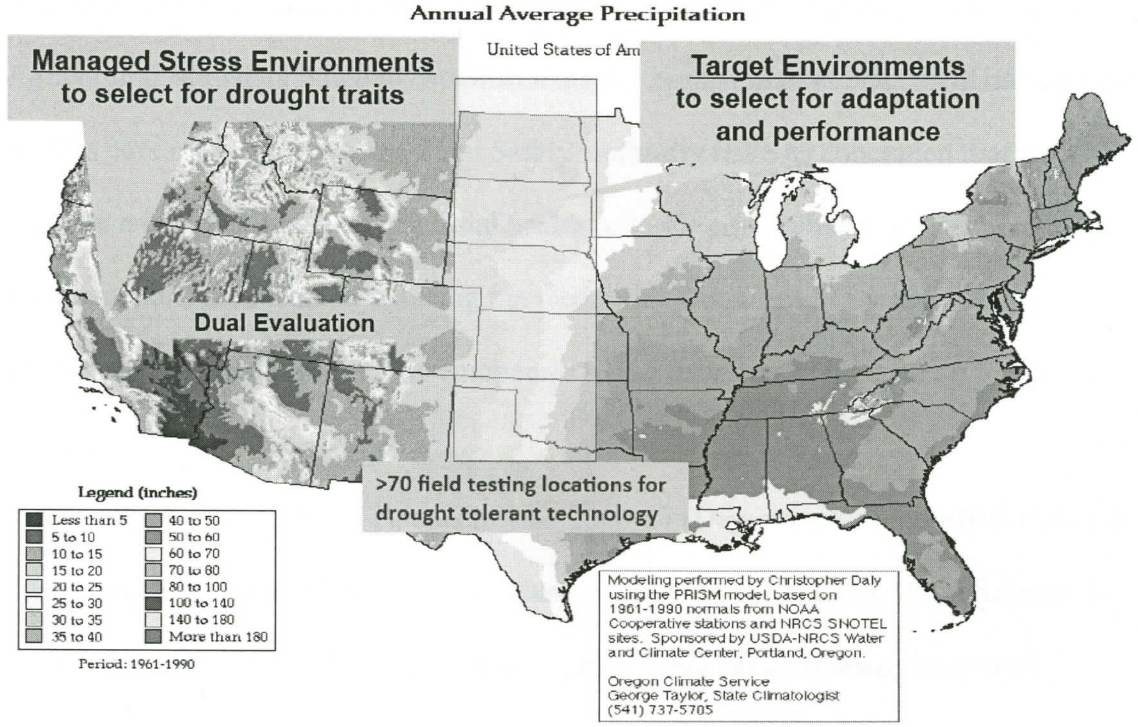


Figure.1.4. Annual Average Precipitation in United States.
Source: Sachs, 2009

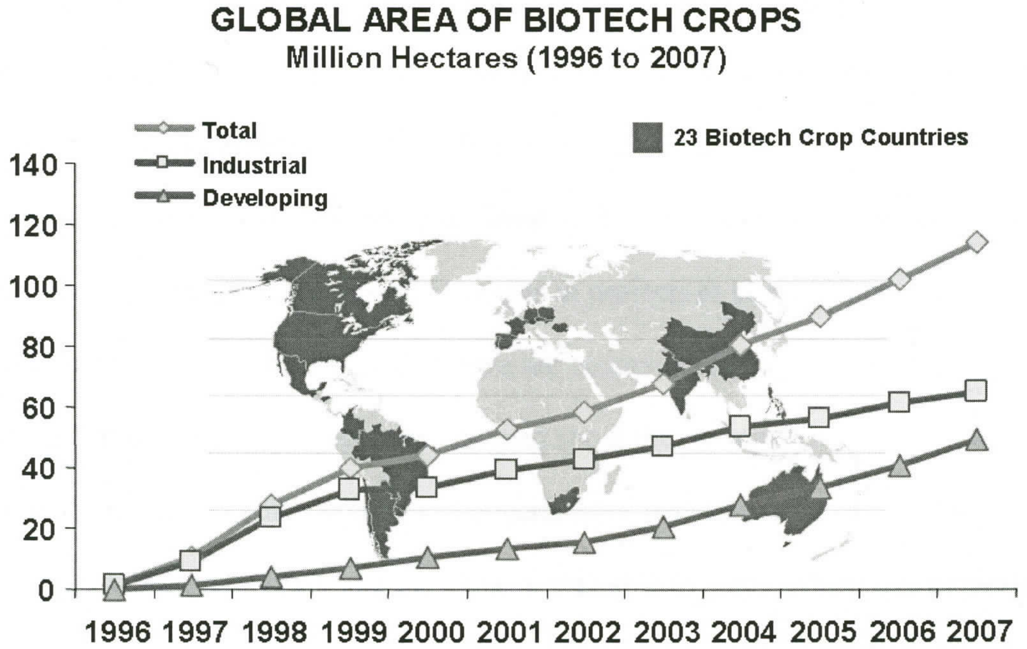
The tremendous growth potential in GM crops is being influenced largely by regulatory systems partly due to legal and mostly due to perceived moral dilemma related with human consumption of GM crops. The policy mechanisms are largely driven in proving the non harmful nature of consumption by humans. Although to date, no harmful effects have been attributed to the cause of crops being GM.

Recently, the European commission has allowed import of GM maize (GA21) into European Union for feed and human consumption. This was done only after Council of Agricultural Ministers failed to establish majority against market placement of GM maize. Studies conducted by European Food Safety Authority (EFSA) concluded that GA21 does not pose any risk to human and animal health or to the environment. This should help European pork producers in reducing the feed costs. Countries like India, is creating amicable environment for private companies to use their research expertise for benefit of farmers.

India granted 15,262 patents in year 2006-07 (Department of Industrial Policy & Promotion, Ministry of Commerce & Industry, Government of India, Press Release, New Delhi, April 02, 2008 RJ/MRS). In its first phase it has set up modern integrated Intellectual Property Offices in the four metros, involving computerization and enhancement of the human resources. The Indian Patent Office has also introduced the facility for e-filing of applications from 20 July, 2007. The Office has also been recognized by the World Intellectual Property Organization (WIPO) as an International Searching Authority (ISA) and an International Preliminary Examining Authority (IPEA) under the Patent Cooperation Treaty (PCT) in October 2007. In second phase, the government of India plans construction of buildings for housing ISA/IPEA operations in Delhi and for Trade Marks Registry and Intellectual Property (IP) Archives at Ahmedabad, substantial increase in human resources to meet the requirements of increased IP filings, digitization of all the IP records, and establishment of a total online office. Separately commencement on setting up a National Institute of Intellectual Property Management (NIIPM) at Nagpur which would cater to training, education, research, and think tank functions in Intellectual Property Rights. These steps are expected to give a big boost to the development and introduction of GM crops in Indian agriculture (Department of Industrial Policy & Promotion, Ministry of Commerce & industry, Government of India, New Delhi, April 02, 2008 RJ/MRS). To evaluate the Biosafety and performance of GM crops, India's Department of Biotechnology (DBT) has provided financial support to set up more than 40 modern facilities to support commercialization of GM crops developed by public sector institutions in country (International Service for the Acquisition of Agri-biotech Applications. 2007. "*State-Of-The Art Biotech Support Facilities In India", Crop Biotech Update, April 4 2008,* Manila, Philippines). China has allocated $1.4 billion for research on GM crops by end of this year 2008, with emphasis on yield quality, nutritional value, and drought tolerance mainly in crops like rice and wheat. (International Service for the Acquisition of Agri-biotech Applications. 2007. *China To Increase Funding for GM Research, Crop Biotech Update, April 4 2008,* Manila, Philippines).

In countries like France where Supreme Court has upheld the ban on Bt maize MON810 against a motion raised by National Maize Growers Association (AGPM), Monsanto, and Pioneer, doubts are on the safety on biotechnological grounds are the impediment to planting of GM crops. The AGPM has estimated the yield loss of 10 million Euros due to insect-pests and increased cost of other plant protection measures.

Apart from research and development costs and the time that it takes to develop a variety, the regulatory policies, and general perception among end and non-end users plays a significant role in deciding the benefit of the GM crop. This in-turn affects the overall the cost benefit aspect of any one or more GM trait included in the crop. The Australia has recently decided to issue license for controlled release of about 30 wheat and barley



GLOBAL AREA OF BIOTECH CROPS
Million Hectares (1996 to 2007)

Increase of 12%, 12.3 million hectares (30 million acres), between 2006 and 2007.

Figure.1.5. Area Of Biotech Crops From 1996 To 2007 (In Million Hectares) Showing Relative Distribution Around Globe.
Source: Clive James, 2007, ISAAA Brief 37-2007.

lines, aimed at higher tolerance to abiotic stresses like drought tolerance, high soil boron levels, and high dietary fibers (Department of Health and Ageing, Office of Gene Technology Regulator, DIR 077/2007). The trial will be conducted by University of Adelaide, Australia and is planned at single site in area under government of Marion, South Australia on a maximum area of 400 m^2 between June 2008 and June 2009. Four of the wheat lines are aimed at drought tolerance. This is significant decision by any government allowing limited release of GM varieties as of today aimed at use for consumption as food.

Use of Real Options

As opposed to real assets and commodities in financial markets, there is no set price, date, or quantity known for future unit sales of research and development of traits in agbiotechnology. Also, it is difficult to predict the possible discoveries and failures during research and development (Paxson, 2001). The common denominator however is that the future is uncertain and there is risk associated with investment in development of traits, but with time the management can make changes in projects to be continued, halted, abandoned or sold to other. Such decisions are become easier to make with time when more and more uncertainty has been resolved about the outcome of project as well as the market externalities. This resolution of uncertainties with time has value to the management (Merton, 1990) and the choices available to management can be treated similar to the options of buy or sell available to a position holder in a financial market. The management is always under pressure to make as much accurate decision as possible due to the time and money involved in development of trait, beside competition in a highly concentrated market.

The risk and uncertainty associated with the research and development of trait are treated in a similar fashion as the price movement of stocks in option pricing theory in financial markets. Some of the problems associated with valuing research and development options (Paxson, 2001) are:

- Identifying the stages of research and development flexibility and action.
- Modeling the duration, dimension, and diffusion process of the eventual payoff.
- Dealing with the uncertainty in the research and development budget.
- Identifying the time varying volatilities of the process and the underlying values.

- Incorporating the probability of success or failure into the model.
- Assuming the eventual product or process will be perpetuity, without preemption or competition.
- Data on research and development is rarely available to the public.
- More the volatility of research and development outputs, more is value of the option. This is because high returns can be generated and extremely low returns can be avoided by appropriate reaction to change in conditions.

Use of real options in valuing research and development was done by Jenson and Warren (2001). They analyzed lifecycle of an e-commerce project and its different stages. In first stage, firm incurs costs for research and market development. In second stage, additional expenditures are incurred in market development. In last stage comprises of implementation phase that constitutes commitment to ongoing expenditure for the rest of project life cycle.

The methodology of real options used is compound call option, where in the research phase buys the option to launch the development phase which in turn buys one the option to advance to implementation phase. The authors refer to Geske Model (1977, 1979) and Perlitz interpretation (1999) to solve such a compound option problem. The model results are either in-the-money (when expected cash flows exceed the cost of three stage development process) or out-of-money (if otherwise). Authors note the value of uncertainty in their model. Volatility for typical e-commerce project is 100%, however when they solved the problem in terms of large diversified firm with less volatility, the option value decreased significantly.

Seppa and Laamanan (2001) used the real options analysis to value venture capital investments. Authors derive the risk return profile of stages of venture capital investments in information technology, biotechnology research, and development enterprises. Three major options portrayed in venture capital investments are: option to abandon investment, revalue the project, and the option to further increase the capital investment. Their Study tests the binomial options based valuation model with large sample of venture capital investments. The authors their empirical model to be consistent with previous knowledge on risk return profile of venture capital investments. They also found that their model had predictive power for actual future valuations.

Organization of Thesis

Chapter 2 describes a typical process of research and development GM trait that may be relevant to reader and review of previous literature relating to the problems addressed in this thesis. Chapter 3 provides a theoretical description of the foundation of real options model building. Chapter 4 provides methodology and results on farm budget and trait evaluation. Risk premiums are calculated across different risk averse attitude of growers is then treated as input in subsequent chapter. Chapter 5 provides GM trait option, model, methodology, and results. GM traits in crops are valued at each stage of development. Chapter 6 provides summary, implication, and limitation. Supporting literature and some detailed results are presented in Appendixes at the end. Appendixes provide complete results.

The methodology includes a valuation analysis of GM traits at each phase of development using real options. GM crop data, including numerous varieties and technology fees will be used in the model. Data on planted acres of traditional crops will be used in conjunction with planted acres of GM crops to estimate expected trait revenue. Currently available traits will be used as a starting point.

Real options analysis conducted using the binomial model and discrete event simulation. A discrete event system is one in which the variables change only at discrete points in time; whereas a continuous system is when state variables change continuously over time. The binomial option valuation model is based on a simple representation of the evolution of the value of the underlying asset.

BACKGROUND AND LITERATURE REVIEW

Background

Manipulation of genetic material using biotechnology to produce desirable characteristics in next filial generation is one of the major achievements of 21st century. This technology when applied to agriculture to improve farming and increase output has brought in a huge change in the way crops are being cultivated, along with simultaneous debate about their suitability for human consumption. Depending on the trait in consideration GM crops can reduce cost of cultivation to farmer (disease resistance), can provide resistance to abiotic stress (cold and heat stress), and or produce desirable consumer preferences (color of corn). With increasing food, neautraceutical and industrial use of GM products, many firms continue to invest in developing GM traits, a process that takes eight to ten years and up to three years in getting permission for its commercial release. Currently companies like Monsanto are developing stacked traits (group of traits incorporated into single variety). After first GM release in 1996, many studies have been done on the impact of GM crops on environment and agriculture. Despite food safety apprehensions from consumer side, the adoption of GM crops for industrial is growing at fast pace.

Substantial market acceptance of GM crops and food has led to research in several areas supported by active participation of private companies. Based on USDA survey data, HT soybeans went from 17% of U.S. soybean acreage in 1997 to 68% in 2001 and 91% in 2007. Plantings of HT cotton expanded from 10% of U.S. acreage in 1997 to 56% in 2001 and 70% in 2007. The adoption of HT corn, which had been slower in previous years, has accelerated, reaching 52% of U.S. corn acreage in 2007. Plantings of Bt corn grew from 8

% of U.S. corn acreage in 1997 to 26 % in 1999, then fell to 19 % in 2000 and 2001, before climbing to 29 % in 2003 and 49 % in 2007.Plantings of Bt cotton expanded more rapidly, from 15 % of U.S. cotton acreage in 1997 to 37 % in 2001 and 59 % in 2007.

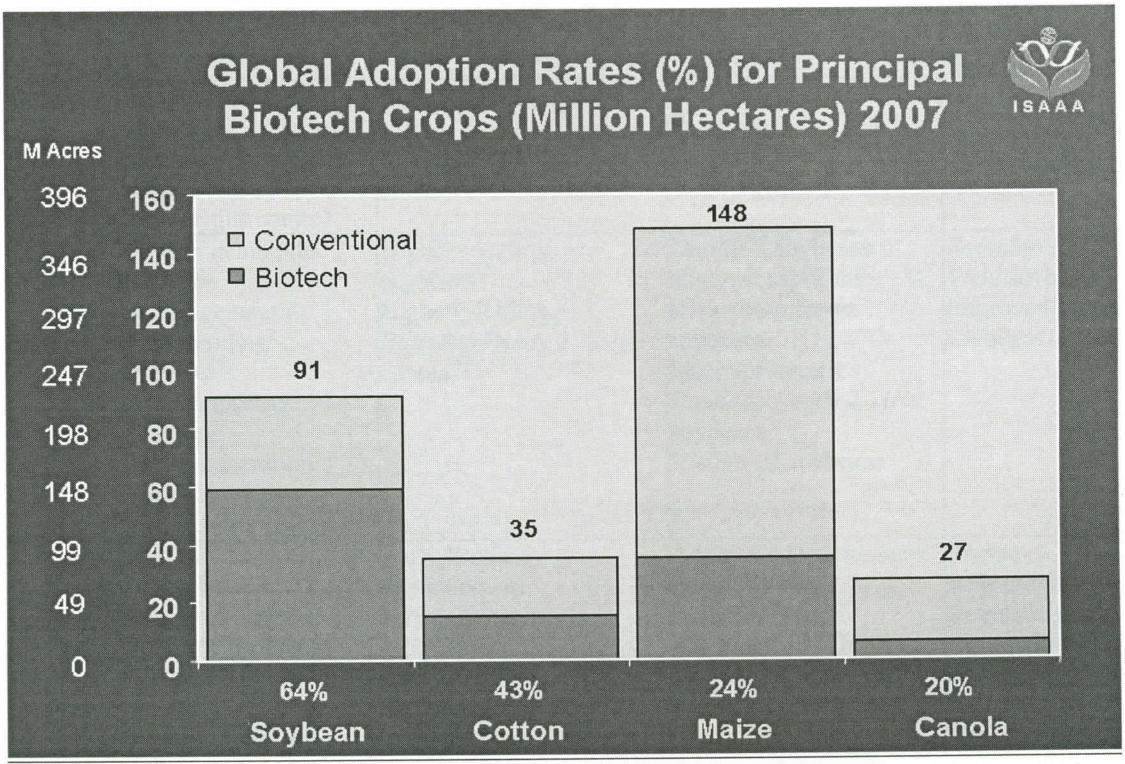


Figure 2.1. Adoption Rates (In Percent) For Soybean, Cotton, Maize, And Canola Crops(In Million Hectares) In 2007.
Source: Clive James, 2007, ISAAA Brief 37-2007.

Current GM traits

Current GM traits include herbicide tolerance, insect-pest resistance in crops, fruits, vegetables, and trees beside plant vigor enhancing traits. Herbicide GM traits include tolerance to glyphosate for example Roundup^R (Monsanto) and tolerance to glufosinate with active ingredient of BASTA^R (BASF). Roundup ready corn and soybean have been very popular. Disease resistance Bt Cotton and varieties of Maize have proven to be of great economical benefits in both developing and developed nations. Many more are in pipeline (Table 2.1).

Table 2.1 Prospective GM Traits Showing Monsanto's 2008 Pipeline.

Monsanto's 2008 Traits pipeline				
	PHASE I	PHASE II	PHASE III	PHASE IV
Corn	*YieldGard* Rootworm III Nitrogen utilization corn(5) High-oil corn	Higher-yielding corn(5) Second-generation droughttolerant corn(5)	SmartStax corn Drought-tolerant corn(5)	*YieldGard VT PRO* Extrax™ corn processing system(4) + Mavera™ high-value corn with lysine
Cotton	Drought-tolerant cotton(5) Dicamba- + glufosinate-tolerant cotton Cotton lygus control	*Bollgard* III		
Oilseeds	Soybean nematode resistance Second-generation higheryielding soybeans(5) Soybean disease resistance Second-generation high-oil soybeans High-stearate soybeans	Higher-yielding soybeans(5) Higher-yielding + *Roundup Ready 2 Yield* canola(5)	Omega-3 soybeans High-oil soybeans Dicamba-tolerant soybeans Insect-protected + *Roundup Ready 2 Yield* soybeans Vistive III soybeans	*Roundup Ready 2 Yield* soybeans Improved-protein soybeans
	Proof of Concept Key activities: Gene optimization Crop transformation Field testing Average duration(2) 12 to 24 months Average probability of success(3) 25 %	Early Product Development Key activities: Large-scale transformation Trait development Pre-regulatory data Field testing Average duration(2) 12 to 24 months Average probability of success(3) 50 %	Advanced Development Key activities: Trait integration Expanded field testing Regulatory data generation Average duration(2) 12 to 24 months Average probability of success(3) 75 %	Prelaunch Key activities: Regulatory submission Seed bulk-up Pre-marketing Average duration(2) 12 to 36 months Average probability of success(3) 90 %

Footnotes to the product pipeline

Pipeline candidates include research platforms in the discovery phase and specific product projects in phases one through four with a higher-than-average probability of success or market potential. The assessment is based on available information and technical progress to date.

Time estimates are based on our experience; they can overlap. Total development time for any particular product may be shorter or longer than the time estimated here.

This is the estimated average probability that the traits will ultimately become commercial products, based on our experience. This figure applies to all product candidates in each phase, not just the candidates listed here. These probabilities may change over time.

This product candidate is in the Renessen pipeline. Renessen is a Monsanto/Cargill joint venture.

This project is part of Monsanto's collaboration with BASF focused on yield and stress research.

Commercialization depends on multiple factors including successful conclusion of the regulatory process.

Beside land grant institutes, private firms, and charity organizations are also t to

plant cellular and molecular biology at Ohio State University (Research news, Ohio State

University, June 30, 2008). The same organization has entered into public-private partnership African Agricultural Technology Foundation (AATF) to develop drought tolerant maize varieties for Africa in partnership called as Water Efficient Maize for Africa (WEMA). The immediate goal for WEMA has been to develop drought tolerant maize varieties for small scale farmers in Africa (AATF, 2008).

Bt. Corn and Soybean

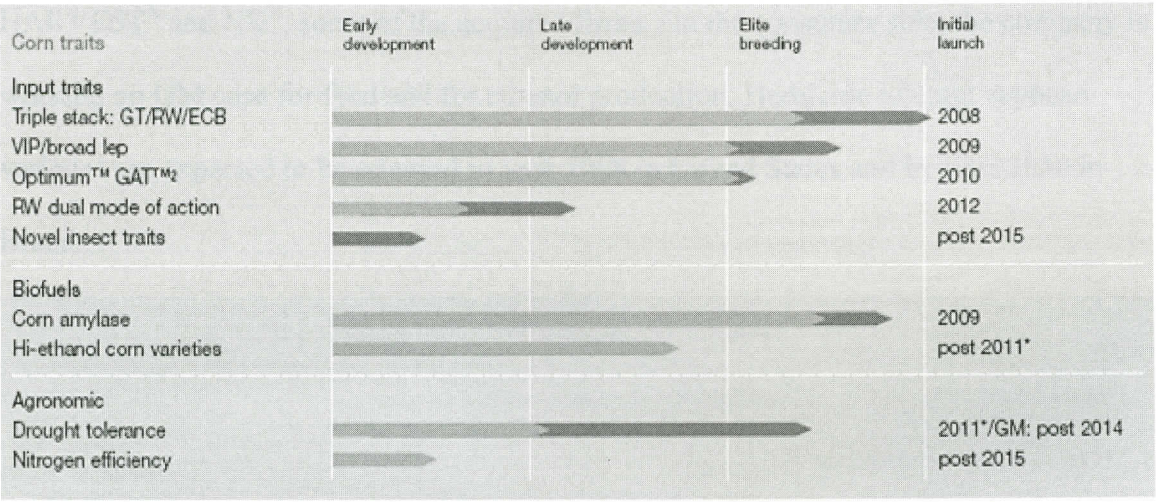


Figure 2.2 Corn Traits in Pipeline: Syngenta.
Source: Syngenta (2007)

The National Biosafety Committee (CNBS) in Brazil ratified a decision grating authorization for sale of corn having Bt11 trait for control against 'Fall Armyworm' and 'Sugarcane Borer' (www.syngenta .com). The company already has been allowed to release GM crops in countries like Argentina, Philippines, United States, and South Africa. It has approval for imports into European Union. Syngenta is also working on incorporating stacked traits in corn and soybeans. The company is hopeful of releasing three traits in a single variety in year 2008 and drought tolerance variety of corn in year 2011. Syngenta along with its partner firms is using biotechnology, conventional plant breeding practices, and marker assisted breeding to work with field crops, vegetables crops as well as flowers. In field crops the research is mainly aimed at disease resistance, increasing nutritional requirements, and enhancing cooking, baking, and brewing qualities for processors and consumers. In vegetables the company is focusing on consistency in appearance, texture, and taste. With increasing popularity of GM corn, the Syngenta if supplying varieties of corn that offer resistance from leaf and soil insects. It is planning to include stacked traits with germplasm from combined entity of GARST^R, GOLDEN HARVEST^R and NK^R, some of the acquired firms. On the consumer side, the company is working on GM corn for feed and for ethanol production. Herbicide tolerant soybean varieties are expected to be released in year 2009 in United States and by year 2010 in Brazil.

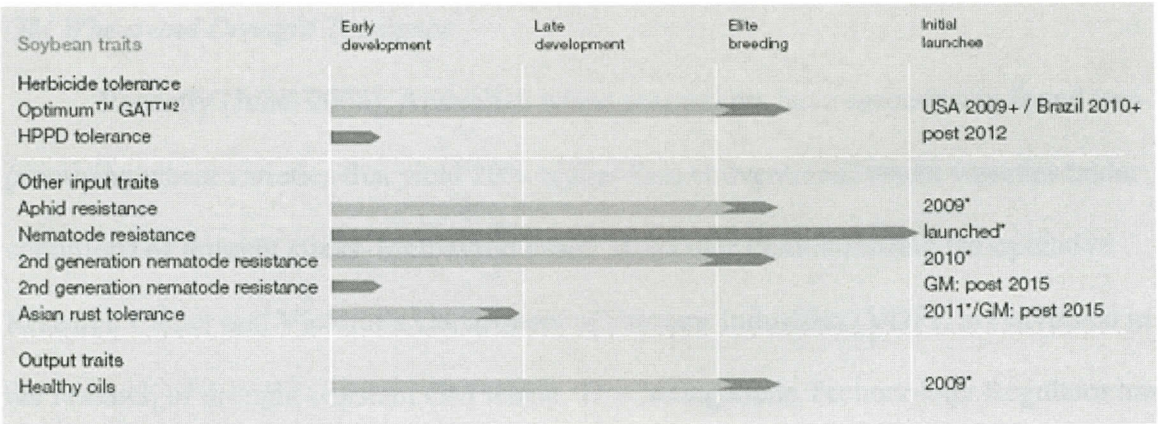


Figure 2.3 Syngenta: Soybean Traits in Pipeline.
Source: Syngenta (2007)

For the first time, GM wheat has been allowed to undergo field trials in Australia, under the aegis of University of Adelaide.

Bt. Corn and Maize

A gene named *Cry1Ab* that provides natural resistance to maize against corn borers is added to corn plant's genome. The *Cry1Ab* gene produces protein that helps against damage from the insect. The gene is originally derived from a bacterium *Bacillus* *thuringienesis*, which has become a commonly used gene in plants for crop protection purposes.

For tolerance to glufosinate ammonium herbicides, the marker gene (*pat*) derived from soil bacterium *Streptomyces viridochromogenes.* The Bt-11 maize produces Bt protein in various parts of plants like leaves silk and stalks, throughout the plant life, thus saving it from insect-pest attacks.

Countries that have allowed the commercial planting of Bt corn include US, Canada, Argentina, Japan, South Africa, Uruguay, and European Union. The countries like Switzerland, Philippines, Taiwan, China, Korea, New Zealand, Russia, and Australia have even approved the Bt corn safe for human consumption (www.syngenta.com).

GM Wheat and Drought Tolerance

Recently (June, 2008), Australian wheat researchers have successfully found two promising wheat varieties that yield 20% higher than conventional wheat varieties under conditions of drought stress. Melbourne based Molecular Plant Breeding Co-operative Research Center and Victoria's Department of Primary Industries (VDPI) are involved in the research of drought resistant GM wheat. The Acting Gene Techonology Regulator has given the license to VDPI for limited and controlled release of up to 50 lines of GM wheat lines for drought tolerance (Office of Gene Technology Regulator Department of Health and Ageing, Government of Australia, DIR 080/2007, www.ogtr.gov.au). Although as of now, none of the produce from GM wheat has been allowed for human consumption or animal feed.

Australian researchers emphasized the increase of more than 20 % GM wheat lines under drought stress conditions at 'BIO 2008 Conference', organized by Biotechnology

Industry Organization, in San Diego, CA held in June 2008. The project leader for trials Dr. German Spangenberg pointed out that as many as seven GM wheat lines out of 24 tested, have provided higher yields in drought stress. Yield from two lines was 20 % more than controlled experimental variety. Such trials would be of immense help for 35 to 50 % of wheat producing areas that are facing risk of drought all over the world in alleviating food shortage (U.S.Wheat Associates, ‘Wheat Letter’, June 26, 2008, www.uswheat.org).

Literature Review on Real Options

The traditional methodology for arriving at profitability of an investment in a long term project under uncertainty has been the discounted-cash-flow (DCF) or net-present-value (NPV). However, the NPV and DCF approach inherently fails to capture the dynamic change in risk associated due to the ability of management to delay, abandon, reverse, or continue with the proposed operating strategies as and when more certainty is achieved. The uncertainty is likely to reduce over a period of time (over the age of investment). Management is likely to have more information with passage of every stage and therefore will take steps to maximize upside potential profit and minimize downside loss. Similar views have been contended by Trigeorgis and Mason, (1987) who said “basic inadequacy of the net-present-value (NPV) or discounted-cash-flow (DCF) approaches to capital budgeting is that they ignore, or cannot properly capture, management’s ability to reverse its original operating strategy if and when uncertainty is resolved”.

Alternatively, simulation and or decision tree analysis can be used to overcome the limitation of DCF and NPV, if the uncertainty is resolved at a constant rate, under all stages, over a period of time. Constant risk adjusted rate accounts for the constant resolution in uncertainty. This approach becomes inappropriate when decisions of investment are made subsequent stages and such decisions are highly influenced on the outcome of previous stages.

Such limitations can be well accounted for by considering the investment under uncertainty as a group of "options" on real assets. The real options approach uses the framework of 'options pricing theory'. An option gives owner the right to buy or sell an underlying asset at some specified time in future for a specified price. The basic idea of using option pricing theory is that under uncertainty of investment in future, the flexibility of making decision after resolution of some part of uncertainty becomes important and has a value. The option pricing theory is an appropriate approach to determine that value (Merton, 1990).

Real Options in Agriculture and Biotechnology

Scarce work has been done in the field of pricing and valuing. Many studies have focused on the benefits of GM crops and varieties and their trend of adoption. The studies focus on traits that are certain and predictable and are easily visible to users and these traits have been the main theme of marketing by various firms.

The following section provides significant wok done relevant to agbiotechnology in the past. The section is organized to present preceding studies conducted using real options as valuation methodology followed by literature review on real options and their applicability to agriculture and biotechnology. While pricing and valuing of traits that are nonrandom is relatively easy, and has been subject of a number of studies, however, similar work has not been done on GM traits that provide value sporadically.

Investing in technology is a calculated risk that an organization or a firm takes with expectation to make profits from it in future time. It can be either pursued till the time of commercialization of technology or it can be licensed to some other firm, in case the original firm thinks it's more profitable to do so. The optimal time to license a technology that involves considerable amount of time and money is also affected by the externalities of adoption. For example, Monsanto's release of GM wheat in US was put on hold by the company's management due to resistance from customers in Europe and Japan, who are primary consumer of US wheat exports. The release of GM wheat is likely to have huge impact on environmental and market externalities.

The policy makers of US and Canadian government, especially, face the task of accounting for the uncertainties in consumers response, externalities associated with environmental impact, the irreversible nature of investment in technology by firms, and its impact on market and justifying their decision to go ahead with the release of GM wheat when most other countries are following a wait and watch approach. Use of real option theory is one such way to reach a convincing decision.

The decision of the government is affected by the expected loss mainly from the consumer resistance to GM wheat both at home and abroad. The market of wheat is affected by the worries of effect of GM wheat on human health in the long term. Although, no scientific study mentions any ill effects associated with consumption of GM wheat in particular, by humans. The environmental dilemma associated with release of GM wheat is its control. Since the GM wheat is resistant to a common herbicide Roundup, it poses a challenge of additional cost of herbicides to control its unwanted spread, to both who adopt and do not adopt GM wheat. Specially, the release of GM wheat will cause an additional cost to non-adopters in terms of controlling spread of GM wheat into their fields (Downey and Beckie, 2002). Once a GM wheat variety is released, a single acre would produce millions of seeds with enough probability of being dispersed into non-GM fields. The dispersion can be at harvesting stage in field, through equipments, during transportation, and or through natural pollination agents like wind, water, and birds. This situation will further become intense in fields where resistant herbicide is used in non-GM field. The GM seeds have tendency to grow better when in competition with non-GM seeds in a non-GM field and when roundup herbicide is used.

There are two irreversible costs associated with production and licensing of GM wheat varieties. The first is related with loss in existing market due to expected reduction in collective producer price. If no segregation cost of GM and conventional crop is assumed, the price discount in market loss will affect both who adopt GM and those who do not (Furtan, et al., 2003). The second cost is associated with control of volunteer GM seeds in future, contributing to the environmental cost. The environmental cost is influenced by the other crops in rotation being GM or non GM and the tillage practices followed in addition to the different levels of herbicide required to used in subsequent years (Furtan, et al., 2003). Their study concludes that without accounting for lemon characteristics of the new technology, the policy makers have insufficient information to make any decision regarding licensing of GM trait. The economic impacts are greatly influences from the market acceptance of new GM variety. A possible suggestion is to label the final products which use GM crops as their ingredients. This would allow consumers to make a choice between GM and non GM food products. Such system essentially would increase the cost of farm to producee as it would need efficient channel of segregation as well as identity preservation and traceability. This may possibly mean separate equipments, elevators, and separate chain of handling and processing. The feasibility of this new separate channel will be decided by expected costs benefits in future. The authors further conclude that the large gain to the biotech firm is more than the loss incurred to producers. In such case, compensation principle gains more relevance. The adopter producers can be benefitted if the biotech firm reduces its technology fee. Also, all the market participants can be benefitted with licensing of GM crop if compensation is paid to non-adopters for their market loss.

The other aspect of market scenario is the expected royalty price rise to the non-adopters. With introduction of GM crops, the prices of herbicides used in conventional crops are likely to decrease. This reduces the cost of production for non-adopters. In addition, due to possibility of demand from consumers who are willing to pay more for non-GM products gives enough incentive to non-adopters to continue with conventional varieties (Huso and Wilson, 2003; Flagg and Wilson, 2008). Physically, there is no difference in GM and non-GM wheat seeds. However, the presence of GM seeds in non-GM wheat is bond to affect the market price of the lot. (Akerlof, 1970) described the existence of a lemon market when there is unavailability of sufficient information for products with different values to consumer in the market place. The only way out is segregation which leads to additional cost of segregation and the problem of sharing that cost between producer and buyer. It also increases the importance of testing while buying and selling.

One of the methods adopted by Monsanto, in Brazil, is of awarding for being true and punishing for lying. Monsanto's Roundup Ready^{R} soybeans (Roundup Soybeans) were first introduced in 1996. Since then, the country's government was entangled into conundrum of legalizing it or not in country. Farmers in Brazil, specially, in the southern part smuggled the GM seeds from neighboring country Argentina, and Roundup soybeans were planted on large scale. The plantation in year 2003 constituted up to 80 % of south Brazil. The government had not given the permission to Monsanto to sell the Roundup soybeans, but farmers were using its technology by getting seeds from Argentina, and Monsanto was suffering losses in loss technology fee. On September 25, 2003, the Brazilian government gave approval for planting of GM soybeans for 2003/04 growing season, but still the law had no provision for sale or importation of GM seeds. Faced with the quandary, the Monsanto, adopted the Point Of Delivery (POD) system, where in the farmers paid post-harvest fee for soybeans grown from its Roundup soybeans as a technology fee (Bell and Shelman, 2006). Monsanto started implementation of POD system in January 2004, where in the farmer had the option of 'self declaring' the produce as GM soybeans or not (the elevator would test the sample using 'strip test'). The company expects the acreage of purchased GM seed to be 50 million acres by 2010 (Bell and Shelman, 2006).

Investment in irreversible project under uncertainty has been interest of work by McDonald and Siegel, 1986; Pindyck, 1988; Dixit and Pindyck, 1994. The approach of real options has been used to measure the impact of uncertainty on investments in agriculture sector by Purvis, et al., 1995; Winter-Nelson and Amegbeto, 1998; Carey and Zilberman, 2002. In case of GM crops, the uncertainty arises out of the social acceptability and the compelling forces of meeting global food production, globally. The use of real options theory in case of valuing and pricing of GM wheat is justified doe to the flexibility provided to the decision makers and because it accounts for the uncertainty associated at various phases of development and commercialization of a GM trait.

The crop rotation adopted by the grower has significant impact on the value of GM trait. For example, a GM wheat followed by a GM or non-GM soybean and or canola would greatly affect the cost of crop protection measures to the grower. (Berwald, et al., 2008) studied the effects of crop rotation on potential benefits and its extent across major soil zones in Canadian prairies. The study looks at a crop rotation of four year period and compares with conventional wheat growers with a treatment of 20 % of planted acreage with various herbicides.

'Assure' has been considered as herbicide to control volunteer Roundup Ready crops both for pre-seed treatment and low disturbance tillage practices. The authors assume a higher cost of treatment ($4.94 per acre) for 80% of acreage arriving at cost similar to cost arrived at by Holzman ($3.95). In rotation with Roundup Ready canola following Roundup Ready wheat, the cost estimates of $8.26 per acre has been considered which is double of that used by Holzman ($4.13). Different such assumptions are made for different herbicides used, different tillage practices and different soil zones with various permutation and combinations for crop rotations possible for a period of four years.

Berwald, et al. assume the technology fee of $7.00 per acre, with some variation from $4.00 to $7.50 (Annou, et al.), which is lower than that considered by Holzman ($15 per acre). The study is based on Roundup Ready corn and soybeans, both being single GM trait technology as a reference point that are currently available in market. As of today, many biotech firms are looking at developing group of traits being referred to as 'stacked traits' (Clive, 2007) in a single variety of crop. Berwald, et al. finds that single year benefits are higher than four year crop rotation. This is because of additional cost of controlling volunteer seeds, in the subsequent growing seasons. However, the estimated benefits have been found to be positive at all levels of assumed yield. The estimated benefits (within rotation) to grower range from \$8.67 to more than \$17.96 per acre. The estimated benefit of single-year Roundup Ready wheat over conventional wheat for low disturbance and conventional tillage range from \$7.80 to \$19.00, with variance in technology fee as mentioned earlier (Berwald, et al., 2008).

The adoption of Roundup Ready wheat gives large in profitability at farm level (Berwald , et al., 2008, and Furtan and Holzman, 2003b). However, the policy makers in government and management of biotech firms will need to consider more than just profit at farm level, for example the underlying environmental costs and uncertainty in consumer acceptance for a technology whose cost is irreversible.

Although, more often the NPV approach has been used a standard rule to measure the profitability of an investment based on expected returns in future, it fails to capture the inherent ability of management to make decision at various phases in future. The Industry Working Group on Roundup Ready wheat for analyzing decision under uncertainty is the real options approach, same as used and recommended by Furtan, et al., (2003b) and Berwald, et al., (2008). A detailed explanation to real options approach to decision making, model, and results will be provided in later sections.

Real Options in Agbiotechnology

Little research has been done using real options to value the agbiotechnology development process. However, real options have been applied to other areas concerning GM foods and agriculture. Real options in financial workings of agribusiness companies is gradually being used, especially in hedging risks (market risk and price risk etc) and contracting within suppliers and buyers. Primarily, studies have been done on the adoption of GM traits from the view point of a state or country. There have also been studies on using compounding options to model changes in the food business (Briggeman, et al., 2005). In addition, research has been done on the valuation of international patent rights for agbiotechnology using real options (Nadolnyak and Sheldon, 2002).

Zou and Pederson, (2008) used real options to evaluate investments in ethanol facilities. First they considered real option to expand of conventional ethanol plant and secondly they evaluate the option to choose a production technology from three available options. Their paper assumes a small hypothetical ethanol plant (50 million gallon capacity) and then developing input-output coefficients and annual cash flow projections. This paper also models the option to wait. During early part of period when low profitability and high volatility exists, strategies of waiting to invest are favored until prices and profitability improve. The real option analysis of technology indicated that stover-fueled technology is most often chosen.

Furton, et al., (2003) analyze the optimal time to license an agbiotechnology product, specifically GM wheat, in Canada. They contend that the adoption of GM wheat is irreversible and extends two primary externalities. First, the spread of the new variety into non-GM crop fields imposes additional costs to non-adopters. Second, the potential loss in aggregate market returns due to the lack of effective trait segregation.

The model extends previous research from McDonald and Seigel (1986) into the value of an option to invest in an irreversible project under uncertainty. In the case of GM wheat, the real options value is the social desirability due to externalities and the impossibility of reversing the decision to adopt. The model examines the timing of the license decision for GM wheat.

Calculating the value obtained from the ability to postpone an irreversible investment is similar to the value obtained from holding a call option in the financial markets. The decision maker holds the option to invest now or postpone to a later date. If the value of the option increases, in this case GM wheat becomes more socially desirable, the decision maker has the ability to exercise the option. If the value of the option declines, the decision maker can leave the option unexercised. Deciding to exercise the investment eliminates the value option to wait for more information.

In real options terminology, the option to license a novel product can be characterized as a *timing option*. Timing options occur when the decision maker has the option to delay the investment. The time delay has value because the decision maker is able to wait in hopes of resolving some of the uncertainty associated with the investment. In the case of the release of GM wheat, the time to delay has value because the costs (i.e. negative externalities) have the potential to be reduced.

Flagg (2008), analyzed the developmental stages (five) of a typical GM trait as ‘growth option’ portrayed to be similar to a call option, where each subsequent option depends on reaching certain milestones from previous one. The results are considered ‘in-the-money’ (ITM) or ‘out-of-money’ (OTM). The option will be profitable and thus exercised and investment in developmental stage will be made in ‘in-the-money’. Authors found that BT Corn development options are “In the Money” at all stages of development. However, in FR and RR wheat exhibited out of money options early in development process (when uncertainty about outcome of research is greatest) but at later stages, the same were found to be in the money.

The authors focus on trait development being in the money or out of money assuming the management considers only two options at each stage: either continue to invest in development or abandon the process of research and development. It may be noted that an important leverage that real options provide is ability of not exercising the option that translates to either wait or to abandon. This paper incorporates this additional choice available to management. Option to wait allows management to defer the process of deciding on investing in development or to abandon.

Flagg and Wilson (2008), Berwald, et al. used certain values for technology fees as a source of revenue to a company that invests in research and development of GTM traits. From a company's perspective, the technology fee is source of expected future cash flows. This paper calculates risk premiums that grower would be willing to pay for GM trait, across three different risk attitudes. This perceived value for a GM trait would vary across risk attitudes of growers, depending upon if they risk neutral, slightly risk averse or moderately risk averse. Also, instead of using discrete values for technology fees, a presumed distribution of technology fee is used as input in calculation of option values.

First we calculate the risk premiums across varying risk attitudes of farmers for base case (no GM trait, thus represents conventional crop) and GM traits using SERF methodology (McCarl and Bessler, 1989; and Wilson, et al., 2006). Limited range of risk attitude thought to represent the population of growers was subjectively decided. The methodology and details are presented in Chapter 4. The risk premiums that farmer across certain risk attitude are willing to pay for a GM trait is the potential technology fee that agbiotech company can charge from growers post release. The variability in potential technology fee that a firm can charge from growers significantly affects the option values at each stage and thus decision to continue investing, defer or abandon the process of research, and development of a GM trait. The detail about the methodology and results are presented in Chapter 5.

THEORETICAL MODEL

Introduction

There are numerous methodologies for valuation of new technologies, whose returns in future are uncertain. From simplest (NPV) methodologies to complex ones like use of real options, the basic challenge is to resolve the uncertainties as best as possible. The dilemmas of decision makers are range of 'ifs and buts' that decide the return on investment under uncertainty. None of current methodologies fully account for the risks associated with various possible scenarios in future. The firm may over invest in a technology or trait (in case of biotechnology) that may prove to be a loss at completion, 10 years after investment, but may be profitable if licensed or sold to other firm while at some intermediate stage. Else, a firm may under-invest in a technology that may prove highly profitable in future and thus not able to reap the potential benefits in future.

Any single methodologies can not suffice for better decision making in investment under uncertain future returns. A combination quantitative, analytical, and simulation tools gives a better picture to a decision maker. Such tools can be used simultaneously or or individually to arrive at clear cut conclusion. The choice of tool used will ultimately influence the decision made by the management to invest or not to invest in the new technology. This choice is even more so important when the investment is irreversible (as in most cases).

The real options approach captures the uncertainty and the risk associated with investment as also the various opportunities available to the management during the future course to halt, defer, abandon or continue with the investment. With passage of time, uncertainties are resolved as more and more externalities become known. This resolution of uncertainties has value to the management and helps in better investment decision making. In development of GM trait, a biotechnology firm has to decide whether to invest in drought tolerant wheat (for example) or not. This decision involves huge cost to the firm and is irreversible. As of today, the consumers are wary of accepting GM wheat, for a variety of reasons, although no harmful effects have been attributed to the food having GM crop as ingredient. This poses a risk to the firm, if it should invest in a trait or not even though it has a huge potential to increase food production in world, beside cost saving to farmers in terms of agronomic and crop protection measures. Ignorance and acceptance from end users poses increases the risk associated with externalities in future. The management is more likely not to invest in such technology. After say a period of 6-7 years, the management gets to know with better clarity if consumer's preferences have changed or not. Two possible cases are: first, the consumers are still not willing to accept GM wheat; second, the consumers are no longer opposed to GM wheat. At this point management is in a better position to decide whether to defer, abandon or continue with investment in GM wheat having drought tolerance trait. The firms can chose to defer or abandon in the first case, and continue in the second case. Such opportunities to management in future are similar to holding an option to buy or sell a stock in future. The real options approach takes into account such future choices that can change the return from future on investments made today.

The economic analysis is based on optimum allocation of scarce resources in most efficient manner. Same is responsibility is for the management of firms on regular basis. Before getting into the complexities of valuation methodologies, some of the most widely used basic traditional economic valuation methodologies like neoclassical approaches mentioned in section I. Neoclassical approach has been mentioned for two common variants: user cost of capital and Tobin's q. Discounted cash flow (DCF) and decision tree framework have also been reviewed in this section as both of them play an important role in empirical analysis. The section ends with details of financial options, use of real options approach, and its empirical analysis. Section II includes the empirical model used in this paper, detailing the elements of problem, their organization, and proposed approach towards their resolution.

Section I: Traditional Valuation Methodologies

Neoclassical Approach

Neoclassical models of investment are based on theory of marginal utility. The theory suggests that a firm should invest if marginal cost of capital is equal to or less than marginal return on the capital. Neoclassical models mostly deal with marginal cost of production. The decision to invest is decided based on additional marginal return by producing one more extra unit of product. Two popular variants of marginal economic theory used in investment analysis are: (1) user cost of capital, and (2) Tobin's q.

The user cost of capital, defined by Jorgenson (1963) as the rental rate of capital, derives its value from the purchase price, opportunity cost of funds, depreciation rates, and taxes. A firm's desired capital stocks are determined by the equality of the value of marginal product and the user cost of capital (Hubbard, 1994). Based primarily on the neoclassical model of capital accumulation, the short-run investment behavior of a firm depends on "the time form of lagged response to changes in the demand for capital" (Jorgenson, 1968).

The desired amount of capital stock K^* is defined as a Cobb-Douglas production function with elasticity of output, represented as γ. Thus,

$$K^* = \lambda \frac{pQ}{c}$$

In this case Q represents the quantity of the output, p and c is the relationship between K_t^* and K_{t-1}^* which implies that each period new projects are initiated until the firm reaches their desired level of capital stock. Therefore, firms invest in new projects when

$$I_t^E = w(L)\left[K_t^* - K_{t-1}^* \neq 0\right]$$

Where w(L) is a power series in the lag operator.

The second variant of the neoclassical investment model is Tobin's q, which compares the replacement cost of marginal investment to its capitalized value (Hubbard, 1994). Represented mathematically as the ratio of m and p, where m is the market value of an asset and p is the asset value. The ratio derives its value from numerous variables, including the return on capital and money, marginal efficiency of capital, income, wealth, and the price of currently produced goods. The investment decision is based upon specific criteria of the value of m / p or, more simply, q. Ranked as:

$q > 1$, Firm should invest

$q < 1$, Firm should not invest and should reduce capital stock

$q = 1$, Firm is at equilibrium capital stock

The model implies that in the long-run q should fluctuate around 1 as firms adjust investment to reach their equilibrium capital stock.

The user cost of capital and Tobin's q rely on using the NPV rule when deciding when to take on a specific investment. They also make two key assumptions: (1) that investments made are largely reversible, or have active secondary markets; and (2) that each investment opportunity is an all or nothing situation such that a refusal to invest in a current project eliminates that project for future investment.

Discounted-Cash-Flow

In business operations, firms normally receive cash flows at disparate points in time; therefore, analysis must adjust cash flows to make them equivalent. The time value of money is a basic, yet essential, part of DCF. In order to put cash flows originated at different times on an equal basis, firms must apply an interest rate to each of the flows so that they are expressed in terms of the same point in time. The two most common DCF models are NPV and internal rate of return (IRR).

The NPV method discounts all cash flows to the present and suBTracts the present value of all outflows from the present value of all inflows. In mathematical terms,

$$NPV = \sum_{t=1}^{N} \frac{R_t}{(1+k)^t} - \sum_{t=0}^{N} \frac{O_t}{(1+k)^t}$$

Where
t = Time period
n = Last period of project
R_t = Cash inflow in period t
O_t = Cash outflow in period t
k = Discount rate (cost of capital)

The discount rate, k, is often determined by the opportunity cost of capital or, simply put, the cost of capital. If analysis indicates that any given project has a positive NPV, the firm should commence with investment. However, since capital is limited, the firm can rank projects with NPV > 0, and select the project with the greatest value. Conversely, if the NPV of a project has a negative NPV the firm should not invest. Lastly, when the NPV of a project is exactly equal to zero, the decision is open because the project earns the minimum required rate of return.

IRR takes a slightly different approach to discounting cash flows. Instead of seeking an amount of present value dollars, IRR solves for the interest rate that equates the present value of inflows and outflows. Represented mathematically as,

$$\sum_{t=1}^{n}\frac{R_t}{(1+r)^t}=\sum_{t=0}^{n}\frac{O_t}{(1+r)^t}$$

The r term is the internal rate of return which is then solved. The internal rate of return is essentially the discount rate that causes NPV to equal zero. In most situations the recommendations made by IRR and NPV are the same; however, this is not always the case. For example, when the initial costs of two proposals differ or cash flows are received in different income streams, NPV and IRR will provide conflicting decisions.

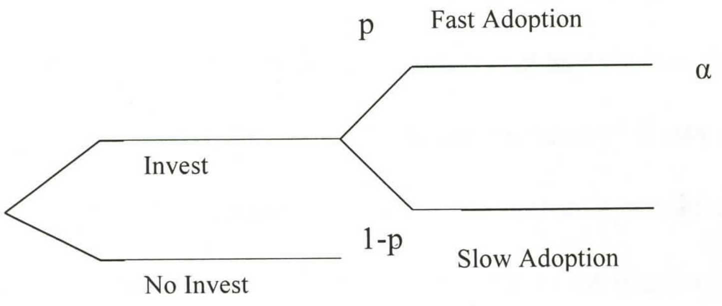
One of the many weak points of DCF are the methods of accounting for risk in the analysis. Typically, risk is accounted for by using a risk adjusted discount rate (RADR) or a certainty-equivalence. RADR is the most frequently used risk adjustment method (Keat and Young, 2003). RADR assumes that the discount rate, k, is the sum of the risk-free rate, r_f (pure time value of money) and a risk premium (RP). However, the methods for acquiring the appropriate risk premium are not exact, and left to the judgment of the decision maker.

The use of certainty equivalence is another commonly used method of risk adjustment; however, there are at least as many short comings in this methods as in RADR. The certainty equivalence works through the numerator of the discounting equation, by applying a factor to the cash flow to convert a risky cash flow to a risk less one (Keat and

Young, 2003). As with RADR, the equivalence factor is left to the judgment of the decision maker, whom in some cases may be biased toward certain projects. This reduces the objectivity of using a certainty equivalence or RADR.

Decision Tree Framework

A decision tree is a visual representation that can help identify all relevant cash flows and their probabilities, thereby enhancing the accuracy and relevance of decisions (Emery and Finnerty, 1997). Decision trees essentially add subjective probabilities to traditional DCF analysis. Decision trees are commonly framed graphically as,



In this example, a firm is confronted with a decision to either invest in the production of a new good or to pass. At the end of the tree, β and α represent the respective payoffs of either fast or slow adoption of the new product, and p is the probability of fast adoption.

Typically, the payoffs of decision trees are either the expected monetary payoff, utility received from the investment and subsequent adoption, or the NPV of cash flows. Decision trees are most easily solved using backward induction, from end to beginning, starting with each final outcome. So, if $(p \times \alpha) > ((1 - p) \times \beta)$ the firm should invest in new product development, if not the firm should not invest.

Traditional valuation methods are useful, but incomplete. Many investments incur numerous stages of development which provides multiple and continuous decisions and subsequent managerial flexibility. Traditional methods alone cannot capture the value of such flexibility or the value associated with the contingent nature of the development process. However, used alongside the options theory, traditional methods can provide more accurate insight into strategic and investment decisions.

Details of Financial Options

There are two basic types of options: the call and put option. The call option gives its owner the right to buy the underlying asset at a specified price on or before a given date. If at expiration, the value of the underlying asset is less than the strike price, the option is considered "out of the money" and not exercised. However, if the value of the underlying asset is greater than the strike price, the option is considered "in the money" and should be exercised (Bodie, et al., 2004). The profit to the buyer of the option (long position) is $MAX(S_t - K - \omega, 0)$ where S_t is the value of the underlying asset, K is the strike price, and ω is the option premium. The profit to the holder can be represented graphically as,

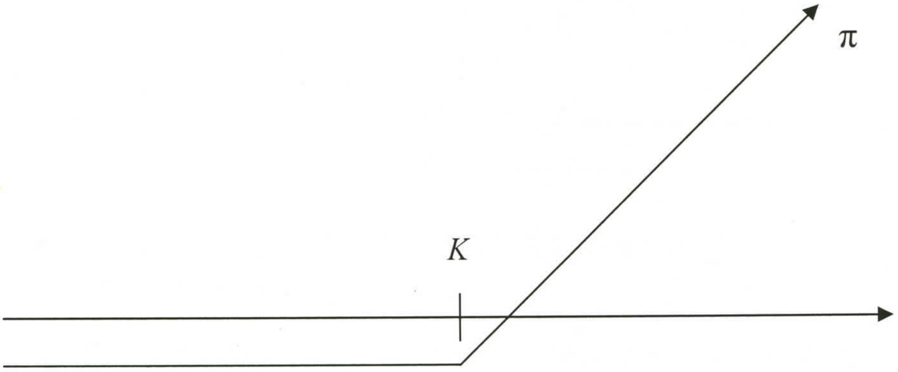


Figure 3.1. Profits For A Long Position In A Call Option.
Source: Damodaran (2005)

For every long position in an options contract, there must also be a short position. The writer of a call option assumes the short position of each call option. According to Hull (2005), the writer of a call option receives cash upfront or, the options premium, but incurs potential liability later. The writer's profit is the reverse of the buyer; thus, $MIN(K+\omega-S_t,0)$ where the writer of the call option is anticipating the value of the underlying asset to be flat or negative.

A put option gives the buyer of the option the right to sell the underlying asset at a fixed price, either on or before the expiration date. If the price of the underlying asset is greater than the strike price, the option is "out of the money" and will not be exercised. However, if the price of the underlying asset is less than the strike price, the put option is "in the money" and should be exercised. The profit of the buyer of a put option is $MAX=(K-\omega-S_t,0)$. The profit of for the holder of a put option can be represented as,

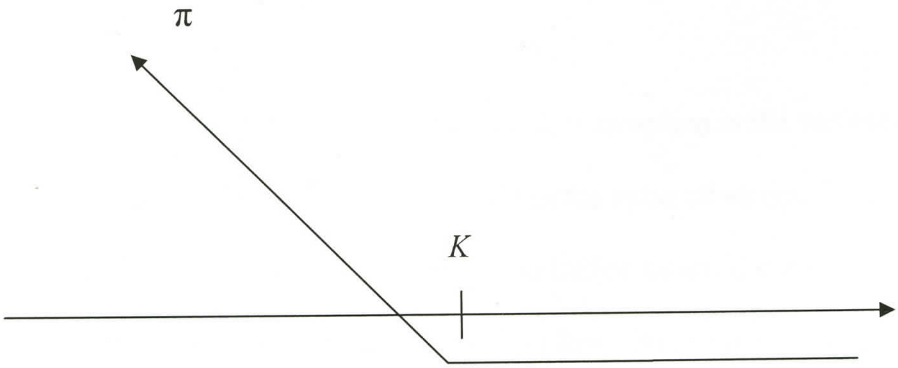


Figure 3.2. The Profit For The Holder Of A Put Option.
Source: Damodaran (2005)

The writer of a put option is anticipating either a flat market or an increase in the value of the underlying asset. As with the call option, the writer of a put option receives cash upfront in the form of the option premium. The profits for writing a put option can be represented mathematically as, $MIN(S_t - K + \omega, 0)$.

The writer of an option contract is exposed to substantial loss. The writer of a call option could, theoretically, incur an infinite loss (there is no ceiling to the price of an underlying asset). However, the buyer of an option contract's loss is capped at 100%, because if the market goes in the opposite direction the option is not exercised and the loss is the premium paid to enter the contract.

Real Options Approach: Empirical Analysis

Option Pricing: Determinants of Option Value

There are six variables that affect the value of an option. First, the value of the underlying asset effects both call and put options, but in different ways. For call options an increase in the value of the underlying asset leads to an increase in the value of the option. Conversely, an increase in the value of the underlying asset will have a negative effect on the value of a put option (Damodaran, 2005).

The second determinant of the value of an option is the variance in the price of the underlying asset. The higher the variance in the value of an option the greater the option value. Although counterintuitive, higher volatility means there is a greater chance of the value at expiration being either very high or low. Since the maximum loss is the option premium, the potential gain from uncertainty overshadows the potential loss. This is true for both call and put options (Hull, 2005).

Dividends paid on the underlying asset also affect the value of an option contract. For example, if a company prepares to make a dividend payout, they have less cash to reinvest in the business causing a decrease in the price of the stock. That being the case, a dividend payout has a negative affect on a call option and a positive affect on the value of a put option.

The strike price and the risk-free interest rate also determine the value of an option. The more the strike price increases the lower the value of a call option and the higher the value of a put option. Conversely, the lower the strike price the greater the value of the call option and the lower the value of the put. Lastly, the risk-free interest rate represents the opportunity cost of funds paid for the options premium.

Put and Call Parity

Put - call parity can be deduced from the arbitrage opportunities which are available to investors. According to Stoll (1969), the best way to analyze this relationship is through the cash flows associated with two portfolios. Initially, the investor writes a call option yielding the positive cash flow *(C)* and the purchase of a put *(P)* results in a negative cash flow.

To go long the investor must borrow V at the risk-free rate (i) for the length specified on the option contract. The interest cost can be represented mathematically as,

$$\frac{V \times i}{(1+i)}$$

The following equation summarizes the previously mentioned cash flows,

$$C - \frac{(V \times i)}{(1+i)} - P = M$$

Where M represents the profits from the arbitrage opportunity. The same sequence can occur for the put option; following the above equation, the put option can be represented as,

$$P + \frac{(V \times i)}{(1+i)} - C = N$$

Where N represents the profits from the above arbitrage opportunity. According to Stoll, in a perfect world with no transaction costs *M* and *N* should be equivalent. The difference in the put and call price is equal to the present value of borrowing at the risk-free rate of interest. Therefore,

$$c - p = \frac{i}{(1+i)} = i$$

Black-Scholes Model

The Black-Scholes model was designed to value European call options with no dividend payments. Therefore, early exercise and dividend payouts have no affect on the value of the call option. According to Damodaran (2005), the value of a call option can be written as a function of the following variables:

S = Current value of the underlying asset
K = Strike price of the option
T = life to expiration of the option
R = The risk-free rate corresponding to the life of the option
σ^2 = Variance in the LN (value) of the underlying asset

The model itself is written as:

$$V = SN(d_1) - Ke^{-rt}N(d_2)$$

Where

$$d_1 = \frac{\ln\left(\frac{S}{K}\right) + \left(r + \frac{\sigma^2}{2}\right)t}{\sigma\sqrt{t}}$$

$$d_2 = d_1 - \sigma\sqrt{t}$$

Determinants in the value of the Black-Scholes include: current value of the stock price; variability in the stock price; time to expiration on the option; the strike price; and the risk-free rate of interest (Damodaran, 2005). Implicit in the Black-Scholes model is the replicating portfolio. Black-Scholes constructed a portfolio of traded securities, known as a tracking portfolio, to have the same payoff as an option (Amram and Kulatilaka, 1999). By the law of one price, two assets with the same payoffs must have the same current value. This ensures that no arbitrage opportunities exist in the valuing of an option.

Binomial Pricing Model

Cox, Ross and Rubenstein first introduced the Binomial Options Pricing method in their 1979 paper titled *Option Pricing: A Simplified Approach* (Cox, et al., 1979). The binomial option pricing model is often represented in a decision tree that follows different possible price paths by the stock price over the life of the option (Hull, 2005). The essential technique in pricing options is to create a package of investments in the stock and loan that will exactly replicate the payoffs from the option.

Hull (2005), explains Figure 3.3 as a sequence of steps. First, consider a stock whose current price is S_0 and an option on the same stock whose current price is represented as f. The stock can either move up to S_0u or down to S_0d in time T. The proportion of upward movement is u-1, and the proportion of downward movement is 1-d. If the price of the

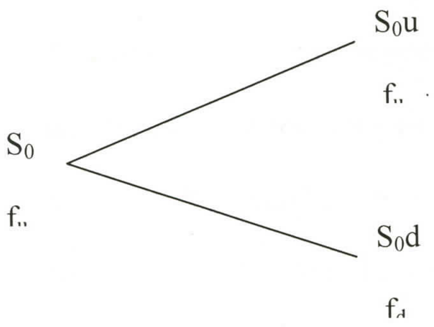


Figure 3.3. Stock Price Movements Represented In A One Step Decision Tree.
Source: Hull (2005)

stock moves up, the payoff for the option is f_u; if the price of the stock moves down the payoff of the option is f_d.

Assume there is a long position in the underlying share of stock, and a short position in one options contract. There is an upward movement in the stock price:

$$S_0 u\Delta - f_u$$

or a downward movement:

$$S_0 d\Delta - f_d$$

This creates a riskless portfolio, and must earn the risk-free rate of interest. The present value of the portfolio is

$$(S_0 u\Delta - f_u)e^{-rt}$$

The cost of setting up the portfolio is $S_0\Delta - f$; therefore, $f = S_0\Delta(1 - ue^{-rt}) + f_u e - rt$.

Substituting for delta and simplifying:

$$f = e^{-rt}\left[pf_u + (1-p)f_d\right] \tag{3.1}$$

Where

$$p = \frac{e^{rt} - d}{u - d} \tag{3.2}$$

Equations 3.1 and 3.2 enable an option to be priced using a one-step binomial pricing model, by solving equation 3.2 and replacing its solution with p in equation 3.1.

The binomial tree analysis can be extended to multiple steps. The objective is to solve the option price at the initial node of the tree, which is done by repeatedly applying the principles established above (Hull, 2005). The length of time T is now replaced with Δt years in the previous equations to account for the multiple steps in the binomial pricing method.

$$f = e^{-r\Delta t}\left[pf_u + (1-p)f_d\right] \tag{3.3}$$

$$p = \frac{e^{r\Delta t} - d}{u - d} \qquad p = \frac{e^{r\Delta t} - d}{u - d} \tag{3.4}$$

Depending on how many steps are in the model, equation 3.3 is repeated. The following sequence of equations represents a multi-step binomial model

$$f = e^{-r\Delta}[pf_{uu} + (1-p)f_{ud}] \tag{3.5}$$

$$f = e^{-r\Delta}[pf_{ud} + (1-p)f_{dd}] \tag{3.6}$$

$$f = e^{-r\Delta}[pf_u + (1-p)f_d] \tag{3.7}$$

Substituting from equations (3.5) and (3.6) into (3.7), we get

$$f = e^{-2r\Delta t}[p^2 f_{uu} + 2p(1-p)f_{ud} + (1-p)^2 f_{dd} \tag{3.8}$$

The variables p^2, $2p(1-p)$, and $(1-p)^2$ are the probabilities that the upper, middle, and lower nodes will be reached. The option price is equal to its expected payoff in a risk-neutral world discounted to the risk-free rate of interest (Hull, 2005).

Real Options and Research and Development

Investing in research and development can be thought of as investing in future opportunities: real options can be used to value such opportunities (Luehrman, 1997). In real options, the thinking behind financial options is extended to real assets, but without imposing any obligation to invest further into a project.

Research and development of a new GM trait, lends itself to the application of the real options framework because the development process is staged and there are measurable risks, and uncertain outcomes to each stage. Like financial options, real options protect the full potential gain of developing a new trait, while reducing the potential loss because of the ability to abandon the project at any one of the five development stages.

The following section introduces the most important types of real options. In addition, there will be an overview of real options valuation methodology; which will include the adaptation of the Black-Scholes model to the pricing of a real option.

Types of Real Options

The key to using real options is the ability to identify the correct application for framing a potential decision (Amram and Kulatilaka, 1998); it should be looked at as, "if we begin our path from point A to point B, what options will open up for us and what will we gain".

There are numerous types of real options, but three are of particular interest for analyzing research and development investments. Timing options, typically, occur when the decision maker has the option to delay the investment. The time delay has value because the decision maker is able to wait in hopes of resolving some of the uncertainty associated with the investment.

The abandonment option arises when firms have the option to stop production or research and development on products whose market opportunities have diminished. The abandonment option fits well with the development of a new GM trait. For example, after the discovery stage of development, the new trait enters the proof of concept stage where they attempt to forecast possible demand. If demand and expected revenue are less than the cost to continue development, the firm can abandon production before entering proof of concept. In this case, the option to abandon has value because the firm avoided further investment into the last three stages, thus, avoiding extra costs for a commercially doomed product. Abandonment options are akin to a put option on a common stock.

An investment includes a growth option if it allows a follow on investment to be undertaken, and the decision to take the follow on investment will be made later based on new information. Such projects are commonly perceived to have strategic value. Growth options give you the right, not obligation, to receive something for a given price; therefore, they resemble the call option.

Sometimes, when looking at research and development it is good to look at the time to build option; which includes staging investment as a series of outlays, creating the option to abandon or grow depending on the arrival of new information. Each stage can be looked at as a call option on the previous stage.

Real Option Valuation Methods

The tools developed to value financial options can be useful in valuing real options embedded in most projects. However, since real options are more complicated than financial options it is imperative to simplify real option analysis to fit financial models. As with all valuation tools, the purpose of real option analysis is to assist in the decision making process, not replace the sound and reasoned managerial functions of a business.

Luehrman presents a simple, yet effective way of using the Black-Scholes model to value real options (1998). One can map an investment opportunity onto a call option, which uses the same value drivers as the Black-Scholes model (Table 3.1). The present value of a project's operating assets to be acquired, represents the stock price; the expenditure required to acquire the projects assets represent the exercise price; length of time the decision can be deferred represents the time to expiration; the time value of money represents the risk-free rate of interest; and the level of risk associated with the project assets represent the variance of returns on stock.

Table 3.1 Map Of Investment Opportunities Onto A Call Option.

Investment Opportunity	Variable	Call option
PV of assets acquired	S	Stock price
Outflow to acquire assets	X	Strike price
Time of deferral	T	Time to expiration
Time value of money	rf	Risk-free rate
Riskiness of project	σ2	Variance of returns

Luehrman creates an option space, using two metrics, to rank and evaluate real options. The first metric contains the data captured in NPV but adds the time value of being able to defer the investment. Luehrman calculates the NPV_q, which is defined as the value of the underlying asset divided by the present value of the expenditure required to purchase them. In Figure 3.4, NPV_q is referred to as the value-to-cost. When the value-to-cost metric is between zero and one, we have a project worth less than it costs; when the metric is greater than one, the project is worth more than it costs.

The second metric is loosely referred to as volatility. This metric measures how much measures how much things can change before the next investment decision must be made. The *volatility* metric is determined by two factors; first, uncertainty of the future value of the asset is captured by the variance per period of asset returns; second, the length of time the investment can be deferred is determined by using the options time to expiration.

Projects are ranked by their location on the option space. If the project has low volatility and low value-to-cost ratio, it is placed in the "never invest" category, but if the project has low volatility and high value-to-cost ratio it placed in the "invest now" category. Rankings are then placed in "maybe now" or "probably later" depending on the level and various combinations of volatility and value-to-cost. Generally, projects with value-to-cost above one are suitable for investment now or have potential for investment in the future.

Copeland presents a framework that is divided into four steps (Copeland and Antikarov, 2003). Step one requires the determination of a value for a "base case" project that has no flexibility built into it using the standard discounted cash-flow. Step two explicitly identifies and models the critical uncertainties involved with the project and understanding the path these values take over time using historical data if available, otherwise uses management estimates. Step three creates a decision tree that can be analyzed to identify the places where management possesses managerial flexibility. Step four uses real option valuation techniques, such as the Black-Scholes or binomial model, to determine the value of the option. The option value is compared to the cost of the option to determine whether or not to make the investment.

Similarly, Amram, and Kulatilaka developed a four-step process for designing and solving real options. The largest source of error made in real options analysis is that the application is poorly framed. Therefore, the first step is to frame the application. The first step includes five critical elements that must be incorporated into developing a good application frame for sound analysis. The second step is to implement the option valuation model that is tailored for the specifics of the application. The primary components of step two is establishing the inputs to the model by calculating the current value of the underlying asset, cash flows, and volatility for each source of uncertainty and obtain data on the risk-free rate of return. Once inputs are established, it is time to select an options valuation method (Black-Scholes etc) and obtain the numerical result.

The third step is to review the results from the options valuation. The valuation results provide several types of results, which include critical values for strategic decision making, as well as results that help quantify the investments risk profile. The fourth step is to redesign if necessary.

Overview of Real Option Theory and GM Technology

Real Option theory addresses many questions that are similar to corporate strategy. It integrates the valuation and decision making over time and uncertainty. The Real Option theory incorporates three elements that are useful to managers (Amram and Kulatalika, 1999): Options are contingent decisions (Amram and Kulatalika, 1999): An option gives the opportunity to managers to decide after a set of events unfold. For example, if the results in preliminary phase of research for traits turns out well, the management will make decision (one) to invest in following phase, however, if the results from previous phase turn out to be bad, the management will decide (different from otherwise) not to invest in following phase. Management may also decide to wait for more information. Amram and Kulatalika thus suggest that payoff to an option is not linear as it changes with the decision.

Option valuations are aligned with financial market valuations (Amram and Kulatalika, 1999). The real option approach uses same concept as that of financial markets and provides results in a common format such that comparison of options available to management (those transactions like to invest, license or abandon the development of GM trait), financial market alternatives and those of internal investment opportunities can be done.

Options thinking can be used to design and manage strategic investments proactively (Amram and Kulatalika, 1999). With Real Option theory approach, one can deduce nonlinear payoffs. Simplest thing to do is to design a strategy in case of best and worst case scenarios or by drawing out a decision tree for possible outcomes. Here, first step is to identify and value the options in a strategic investment as suggested by Amram and Kulatalika 1999. This option can be better modified to proactively manage the investment.

Section II: Model of Berwald, Carter, Huso

Elements of Problem in Model

The main factor that this paper looks at is the randomness of event occurrence. Most of the earlier studies focus on the methodologies that have been used for investments under uncertainties. The uncertainty mainly deals with the future cash flow which has been either discounted or valued using real option theory. However, it has been assumed that the event for which the trait is being developed will happen. It's only a matter of return in cash or the gain in efficiency from that trait that will benefit the farmer or the firm. This paper takes into account the uncertainty associated with randomness of event occurrence. For example, for developing a trait like drought tolerance, the return gained from the trait to farmer or to the firm is the secondary thing, however, this paper will take into account the randomness in occurrence of drought, only in occurrence of which the trait would truly valuable. Flagg and Wilson (2008), do not look at this aspect of randomness of event occurrence at all. Their work assumes that a trait like herbicide resistance, will happen with 100 % certainty, that is, the farmer who buys the herbicide resistant seed is going to use the herbicides for control of weeds and under such conditions, they have arrived at a model that helps management decide if the for such trait is in the money or out of money.

Also Flagg and Wilson (2008) have taken the base case values that are based on theoretical pricing model used by Huso and Wilson (2006). These values need to be revisited in current scenarios which have vastly changed. Therefore, the theoretical pricing model has been used in this paper to put a value on a traits like drought tolerance in wheat that are yet to be commercialized, and then subsequent prices arrived derived will be subjected to real option theory approach to decide if the investment is beneficial or not. The first step is to arrive at expected and acceptable price of traits. Secondly, using the real option theory, decide whether such traits would be beneficial under random event occurrence and up to what extent (the technical efficiency gain). Thirdly, when management of say a firm, has dozens of such traits to be developed at various stages, what approach should the management's decision be based on to invest in the trait. This would also include the current scenarios wherein the companies have stacked traits (more than one GM trait in single variety) in offering.

Flagg and Wilson (2008), used binomial options in their model, which is apt for the scenarios they have considered. Their work deals with a trait that is aimed to benefit the farmer in one way or other, and thereby the firm has a reason to charge a technology fee from the farmer. This technology is main source of revenue which has been used to account for future returns from the investment made in present in development of the trait. This paper differs in the fact that for the traits like drought and cold tolerance, it is not certain if the drought will occur, and thus the farmer would not be certain at the time of buying the seeds. This factor is not included in their model and has been accounted for while deciding the price of the trait as well as while deciding the profitability of trait under development.

The other main thing that Flagg and Wilson (2008) have not included in their work is the supplementary revenue earned from the trait. For example, if the firm develops a trait like NUE, and the same firm sells nitrogen fertilizer, then the revenue of seeds would supplement the revenue from the sale of fertilizer. The same would be the case in traits like Herbicide resistant, wherein the sale of herbicide resistant seed would be one source of revenue, and sale of herbicide itself from same firm is another source of revenue. The benefit from such traits is dependent on the price of fertilizer which is uncertain. Therefore, while deciding about the investment in such traits, it becomes imperative that other such sources of revenue are also taken into account, specially when the supplementary source of revenue is close to the revenue earned from the sale of seeds itself. The extent of revenue earned from supplementary channel becomes more important when the firm like Monsanto has been able to increase the price of Glyphosate by more than 100 % and the margin it earns from it is between 50 to 60% (as per information from various retailers and distributors). This would change the decision of many out-of option stages in the work of Flagg and Wilson (2008) for various traits into in-the-money. Which means just because management did not take into account the possible sources of revenue, it will fail to invest in a technology that would have potentially been profitable.

Real Option Model

The GM technology is an irreversible investment involving stepwise process spread over a cumulative time period of 8 to 10 years(Table 3.2). Each phase has different probability of success and thus management has the opportunity after completion of a particular phase for making decision about the following phase. For sake of simplicity, it is assumed that uncertainty associated with fixed cash flows is resolved at completion of each phase. To better understand the uncertainty and the inherent opportunity available to management, the overall process from identification of a potential economical GM trait, till the time it is commercialized, can be broadly categorized into five development phases as following (more details in Chapter 2 and 3):

- Discovery
- Proof of Concept
- Early Product Development
- Advanced Product Development
- Regulatory phase

At the end of each phase, the management has the option to decide whether to continue, wait or abandon trait development. Every stage involves investment of millions dollars and time span of 1-4 years (Table 4.1). This is consistent with earlier study done (Flagg and Wilson, 2007) to maintain the results comparable. Each developmental stage has different probability of being successful.

Option Value of trait (presented in chapter 5) at various stages was done using ‘Real Option’ methodology. Three possibly options to “continue”, “wait” and “abandon” have been modeled in this thesis. Option to abandon exists at every stage of development.

However, out of other two options, only one of the two can be chosen by the management. This has been done to use same single period probability while calculating option value at any particular stage. As per the published papers, only cumulative probabilities (for the stages considered) are known. Thus in order to use the published probabilities and to make the results comparable with previous studies, binary option model approach is used. The 'continue' growth option represents the decision of management to continue to next stage and make further investment. Management would make such decision in case it is in-the-money. In case the management chooses to wait it would not make any further investment for the period of next (hypothetical but similar to the one in case it had continued) stage. Thus, option to 'wait' for any stage is valued same as option to 'continue' of previous stage with additional time frame of current waiting period added to it. Such valuation of choices of options is helpful for management in better comparing and analyzing the possible scenarios. The possible scenarios indicate the variation in option value of traits at different stages of development had they made the choice to 'continue', 'wait' or 'abandon'. For example, if the management thinks difference in option value of 'continue' and 'wait' is

Table 3.2 Typical Time & Investment Required For Developmental Stages Of A GM Trait.

Trait Development Assumptions	Discovery	Proof Of Concept	Early Development	Advanced Development	Regulatory Submission
Time (in Years)	3	1.5	1.5	1.5	2
Investment	\$3,500,000	\$7,500,000	\$12,500,000	\$22,500,000	\$30,000,000
Cumulative Probability	0.05	0.25	0.5	0.75	0.9
Single Period Probability	0.20	0.50	0.67	0.83	0.90

Source: Monsanto(2008), Flagg and Wilson, 2008, Jagle, 1999.

worth enough considering political and social environment, then option to 'wait' will be a rational choice. Appendix D shows many such choices that can be made by management and how the option value of GM trait varies with every choice made.

Why Real Option is Important

The real option methodology captures the risk associated with each stage of development and takes into account the different choices available to management at the end of each stage. The Discount Cash Flow (DCF) fails to consider the fact that management may chose to wait at the end of any stage and thus a constant expected future cash flow is not a valid case. If a management decides to defer the investment at the end of any stage and then continue, it implies that in terms of research, the trait is at same stage as previously, but in terms of time it has elapsed to next stage. For sake of simplicity, it assumed that if management chose to wait, then the time of wait are equal to the time of next stage of development had it chosen to continue. This helps in drawing out a table of possible paths that management can follow by making different choices at the end of each stage on a parallel basis. The possible cases are presented in Appendix A…. in reference to an ideal case where management decides to continue at all the stages. This way comparison can be made in the change in option value of trait in relation of option to 'continue' and option to 'wait' during same time frame.

What is 'Option'

The management has various choices at the end of any phase of development. It can either 'continue', 'wait' or 'abandon'. How these choices are made affect the future expected returns (FER) and thus the NPV. A constant rate of discounting the future cash flow is not appropriate and representative of actual possible choices available to management. The option value of a GM trait as calculated in this thesis at each stage of development captures the risk of GM trait moving onto the next stage and the gain that particular trait is expected to provide to the farmer. This is so because; the option value depends on probability of success, time taken for the stage, investment made in the stage, adoption rate, and technology fees.

The adoption rate and technology fees affect the NPV of FERs. Previous studies use various values of technology fee and contend their values to be true while disputing the values used by others on the basis of factors like region, soil type, and other savings from agronomic factors. This thesis captures the full distribution of such technology fees for various crops (Table 4.15). The technology fee represents the value reflected from reduced risk as inferred from risk premiums that farmer would be willing to pay for a GM trait(s). This has been calculated using SERF.

Why is it Important

Real Option Methodology captures the two important things. Firstly, it captures the reduced risk that farmer is willing to pay for the GM trait in case there is event occurrence. For example, in case drought happens, farmer can expect less deviation with GM crop relative to conventional crop. This preference of farmer for reduced risk is reflected from the risk premiums (using SERF). The distribution of these risk premiums have been used as inputs in real option model as range of technology fees. This helps including the effect of reduced deviation of output from a GM crop versus conventional crop into the ‘real options’ model. Secondly, the ‘real option’ model better captures risk associated with probabilities of GM trait successfully reaching the commercialization as well as different externalities that pose choices in front of management as whether they should ‘continue’, ‘wait’ or ‘abandon’.

Value of GM Traits Based on Farm Budgets

Risk premium that a grower would be willing to pay to reduce the uncertainty associated with random events like drought are calculated through certainty equivalents. The risk premiums vary with risk averseness of a farmer. This makes up part one of the model presented in this chapter. The risk premium is considered as proxy for technology fee that a company can look forward to charge from grower/farmer. This technology fee is then treated as input for Real Option model that makes up second half of the model presented in chapter 5.

Trait Efficiency

The trait efficiency in case of GM crop should ideally help in reducing risk for the farmer(Table 3.3). In case of event occurrence (for which the GM trait is aimed at), the grower should still get more amount of produce or have more cost savings resulting in less standard deviation in RTLM.

Table 3.3 Typical Efficiency Gains Assumed For GM Trait(s).

Trait	Assumption	Source
Drought Tolerance in Wheat	20 percent more yield than best wheat lines	US Wheat Associates, (June, 2008), ISAAA (2008), and OGTR, Australia.
Drought Tolerance in Corn	GM trait can save 25 percent of losses caused due to drought	Edmeades (2008)
NUE in Wheat and Rice	Varieties under testing require 50 percent less nitrogen or provide 25 percent more yield for same nitrogen	Ridley, (2009)

For trait like Drought tolerance, assumptions are based on recent findings (June 2008) where in Australian wheat researchers have successfully found two promising wheat varieties that yield 20 % higher than conventional wheat varieties under conditions of drought stress. Melbourne based Molecular Plant Breeding Co-operative Research Center and Victoria's Department of Primary Industries (VDPI) are involved in the research of drought resistant GM wheat. The Acting Gene Technology Regulator has given the license to VDPI for limited and controlled release of up to 50 lines of GM wheat lines for drought tolerance (Office of Gene Technology Regulator Department of Health and Ageing, Government of Australia, DIR 080/2007, www.ogtr.gov.au). Although as of now, none of the produce from GM wheat has been allowed for human consumption or animal feed.

Australian researchers emphasized the increase of more than 20% GM wheat lines under drought stress conditions at 'BIO 2008 Conference', organized by Biotechnology Industry Organization, in San Diego, CA held in June 2008. The project leader for trials Dr. German Spangenberg pointed out that as many as seven GM wheat lines out of 24 tested, have provided higher yields in drought stress. Yield from two lines was 20% more than controlled experimental variety. Such trials would be of immense help for 35 to 50% of wheat producing areas that are facing risk of drought all over the world in alleviating food shortage (U.S.Wheat Associates, 2008).

For corn, the assumption for drought tolerance trait has been modified to include the update published in "Feature Article on Drought Tolerance in Maize, 2008". It has been mentioned that 25% of losses due to drought can be eliminated by genetic improvement in drought tolerance, and further 25% by application of water-conserving agronomic practices, leaving the remaining 50% that can only be met by irrigation (Edmeades, et al., 2006). Cold tolerance in corn assumes an increased yield of 5% in yield. NUE in corn assumes a saving of 10% in terms of cost of chemicals. The “All” has 25% saving from losses (in yield) and 10% from cost of chemicals. Similar assumption for trait efficiency are used for Cold tolerance, NUE, and combination of all these traits “All”. In absence of exact published values for trait efficiency in other crops, analysis is based on similar assumption for a GM trait across crops. This is done to maintain consistency. In case there are more than one trait that yields similar benefit to the crop, the highest of the two is considered for “All”. For example, with Drought tolerance there is an increased yield of 20% and 10% with Cold tolerance, then 20% increase in yield is considered for “All” in addition to savings from NUE.

METHODOLOGY ON FARM BUDGETS AND TRAIT EFFICIENCY

Introduction

Development of GM trait by a seed-biotech company is an irreversible decision that involves both endogenous (during developmental phase) and exogenous risk over a period of eight to ten years and investment of millions of dollars. Management has to decide about setting the price of technology fees that can be charged from farmers (company's FER), as well as, most accurate cost of developing the GM trait that captures the risk associated with it and options (flexibility of choice) available at various stages of development.

Traditionally, the DCF has been used to value the cost of development of a GM trait. It is generally assumed that a certain amount of investment is made at various stages in future and then a return from investment is deduced to consider if development of GM trait is profitable or not. However, such studies critically fail to capture the possibility of other choices that a management can make over a period of 8 to 10 years of development. All such choices significantly affect the expected future returns. The management can decide not to continue with investing in next stage of development and rather chose to wait, which may be more beneficial to the company in case they decide to continue after the waiting period. This flexibility of making choices is captured by 'Real Options' methodology.

Previous studies have assumed specific value of technology fees for particular regions and then proceed with discounting cash factor methodology to arrive at profitability of developing a trait given the amount of technology fees and planted acreage. Subsequent papers then dispute the value of technology fee used which according to them is irrelevant in different geographic region. It must be noted that in absence of exact knowledge of strategies used by biotech companies, it is appropriate for economists and management to have idea of a range/distribution of values like technology fees, risk averse attitude of farmers, and cost of developing the trait that captures the risk and various choices that can be made over the period of development. For example, it is theoretically possible for a company to charge different technology fees from different farmers, if it could identify the farmers with different risk aversions. The company can price the GM seed differently in different regions depending on the general climatic conditions and risk averse attitude of farmers.

This thesis uses SERF to model the value of trait to a farmer by calculating the risk premium(s) that a farmer would be willing to pay for GM Trait(s). Instead of using one value of technology fees, this thesis uses a uniform distribution of potential technology fees. This technology fee is then treated as input for revenue in calculating option value of GM trait at various stages of development.

The outputs from SERF are treated as inputs for "real option model" that this thesis focuses on and the results are presented in Chapter 5. A short overview of farm budget model and trait efficiency is mentioned in later part of this chapter.

Model Overview

The overall problem is modeled in two steps. Part one of the problem deals with putting a value to a trait (using SERF) and Part two (Chapter 5) deals with using this value of trait to model the various stages of development of trait (using Real Options) for a company's management. Results from part one are treated as inputs for Part two.

Farm Budget Analysis

Regions Modeled

The budgetary data for purpose of calculating risk premium was used so as to represent the crop. For corn and HRSW South Central western part of North Dakota was used. The underlying assumption is that range of ARACs would be somewhat similar across the country as exhibited by farmers in particular region. Once the risk premium was arrived at, the results from part one are used as input in part of real option model where in the planted acres for USA were used to calculate Option Value of a GM trait. This is for the reason any seed-biotech company would not develop for a small geographic region rather across a large region such as a country like USA and or Canada.

Sources of Budgets, Data and Years

For Part 1, the budgetary farm data from North Dakota State University Extension Dept. was used for the period of 1989 to 2007(Table 4.1).

Table 4.1. Range of Data Used for Corn and HRSW.

Crop	From	Till
Corn	1989	2007
HRSW	1989	2007

For putting a price on a GM trait, the crop budget data from state report of North Dakota Farm Business Management Education Program has been considered from year 1989 to 2007. Yield, price, cost of seeds, chemicals (herbicides, fungicides, and insecticides), and fertilizers are the variables on interest from the data available.

The data for inputs for farm budgets was also taken from Economic Research Service of USDA. Data for planted acreage for corn and HRSW was collected from National Agricultural Statistics Service, USDA (May 2009).

Random variables and Parameters

A budgetary sample is shown in Appendix D. Some of variables that are treated as uncertain and random and play major role in deciding the expected market value of technology fee for a GM trait (which is random and non-persistent) for a seed biotech company are:

a. Yield per acre
b. Seed price
c. Cost of seed
d. Cost of Chemicals
e. Cost of Fertilizers

The historical data for these variables were fitted for their distribution using @risk (Palisade Corporation) and also the correlation between the variables. The correlation was tested for statistical significance and then only statistically significant correlated variables were allowed to change in same distribution of random values in relation to other variables. Drought Years in historical data were arrived at subjectively. It was done in order to avoid getting into intensity levels of drought in different regions for the same crop. Eight years were found to be drought years out of the data set for 19 years and thus in real option model, a drought probability of 8/19 years (=42) is used to test if it has affect on option value of GM trait at various stages of development. Drought is assumed to be the major reason for decrese in yield.

Correlation Between Random Variables in Corn

For crop of corn, the GM traits considered are: “Drought tolerance”, “Cold tolerance”, “NUE”, and all the traits combined into one “All”. In order to arrive at risk premiums for GM traits that farmer would be willing to pay, the randomness was allowed in the same order (distribution) as in historical data. The variables were tested for correlation and significance of each was considered. The correlation and significance once calculated was then used for base case and all the other cases of GM trait in similar fashion to maintain consistency. The correlations and significance for corn are presented in Table 4.2 and 4.3.

Table 4.2. Correlation and Significance of Variables in Corn.

	Yield	Price	Seed	Chem	Fert
Yield	1.00				
Price	0.10	1.00			
Seed	0.33	0.41	1.00		
Chem	0.37	-0.31	-0.22	1.00	
Fert	0.39	0.45	0.94	-0.03	1.00

In corn, only seed cost and cost of fertilizer were correlated with correlation coefficient of 0.94 at 95 % significance. The same correlation coefficient was used while creating randomness using 'riskcormat' function in @risk.

Corn: Base Case

In base case, Yield, Price, Seed cost, cost of chemicals, and cost of fertilizers were treated as random, and return to labor and management (RTLM) was calculated for 10,000 iterations. No assumptions in terms of gains owing to GM trait were applied in base case. The base is what a conventional variety without GM trait performs. The distribution of random variables was same found in historical data set through 'fit distribution' of @risk. The distribution of RTLM and tornado graph of regressed variables is presented in Figure 4.1.

Table 4.3. Correlation Coefficient T-Values. Bold Values Indicate Statistical Significance At The Specified Level (In Corn) (significance level=95%, t-critical=2.11).

	Yield	Price	Seed	Chem	Fert
Yield		0.42	1.45	1.65	1.75
Price	0.42		1.85	1.34	2.06
Seed	1.45	1.85		0.94	**11.12**
Chem	1.65	1.34	0.94		0.11
Fert	1.75	2.06	**11.12**	0.11	
	Yield	Price	Seed	Chem	Fert
Yield	1.00	0.00	0.00	0.00	0.00
Price	0.00	1.00	0.00	0.00	0.00
Seed	0.00	0.00	1.00	0.00	0.94
Chem	0.00	0.00	0.00	1.00	0.00
Fert	0.00	0.00	0.94	0.00	1.00

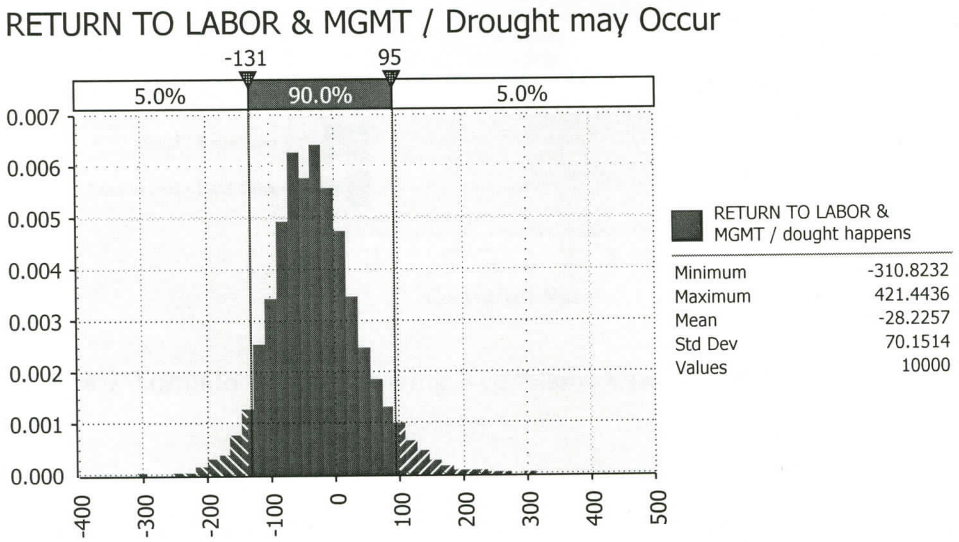


Figure 4.1 Probable Density Distribution for Base Case in Corn.

The RTLM for Base case was 90 % of times found to be between -132 to 95, which means that return to labor and management varies between a loss of $132 on the downside up to profit of $95. The variables that affected RTLM most are presented in Figure 4.2. Yield was found to have maximum positive impact on RTLM in base case (value of .85) followed by Price (.50).

Corn: Drought Tolerance

Drought tolerance in Corn assumes that loss of 25 % can be prevented through GM trait (Edmeades, 2008). The probability of drought considered in this paper has been assumed to be 42 %. This probability of drought is same as 8 years of drought out of 19 years of historic data used for the corn. Drought occurrence in model has been treated as discrete distribution with 42 % probability of occurrence. The RTLM was calculated as before in Base case and probability distribution is shown in Figure 4.3

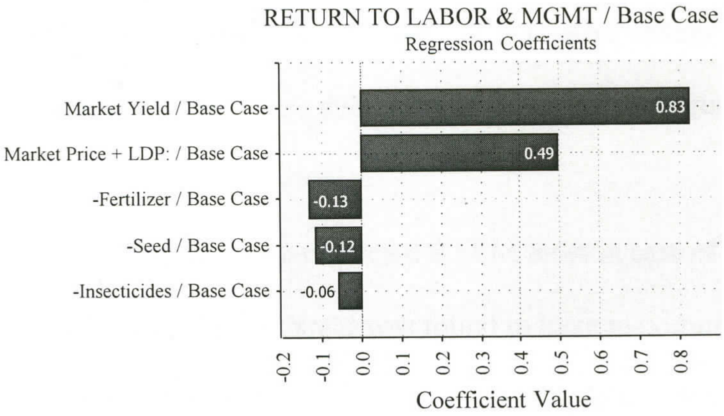


Figure 4.2 Tornado Graph Showing Regression Coefficient for RTLM in Corn (Base Case).

The RTLM for Drought Tolerance was 90 % of times found to be between -128 to 103, which means that return to labor and management varies between a loss of $128 on the downside up to profit of $103. There is an improvement of $4 in downside and $8 on the upside in Drought Tolerance relative to the base case. This improvement, although slight, is solely because of 25 % saving in loss due to GM trait under drought conditions over conventional variety. The relative change can be seen from cumulative distributions of Base case and Drought Tolerance in Figure 4.4.

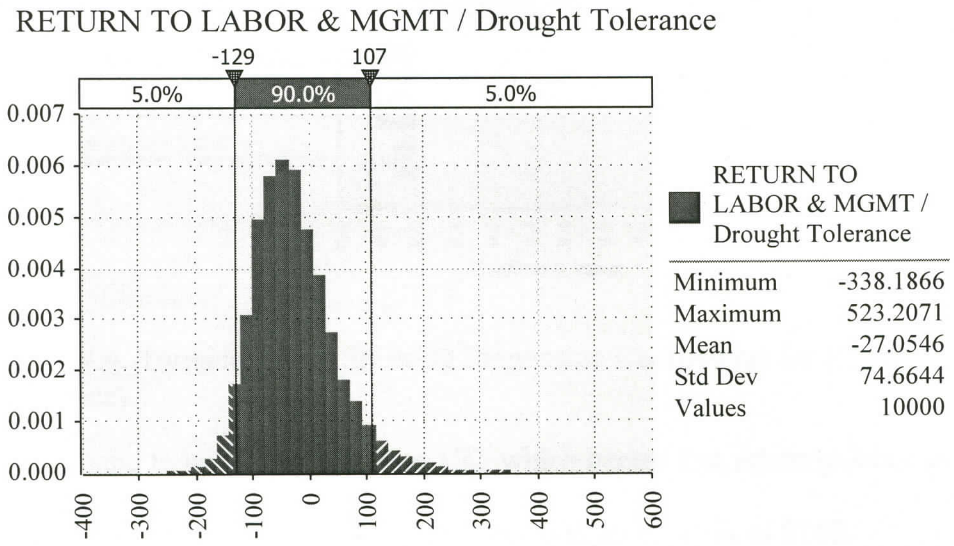


Figure 4.3. Probable Density Distribution for Drought Tolerance in Corn

The variables that affected RTLM most in case of drought tolerance in corn are presented in Table 4.8. Yield was found to have maximum positive impact on RTLM in Drought Tolerance (value of .86) followed by Price (.45).

Corn: Cold Tolerance

Cold tolerance assumes an increase in Yield by 5 % under cold/frost conditions. All other variables were treated same as in Base case. The probability distribution for RTLM in Cold tolerance is presented in Figure 4.5. The RTLM for Cold Tolerance was 90 % of

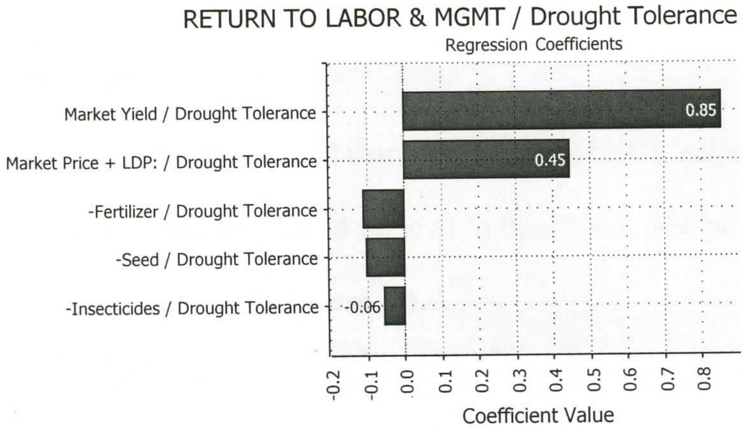


Figure 4.4. Tornado Graph Showing Regression Coefficients for RTLM in Corn (Drought Tolerance)

times found to be between -130 to 102, which means that return to labor and management varies between a loss of $130 on the downside up to profit of $102.

The variables that affected RTLM most in case of Cold tolerance in corn are presented in Table 4.10. Yield was found to have maximum positive impact on RTLM in Cold Tolerance (value of .83) followed by Price (.50).

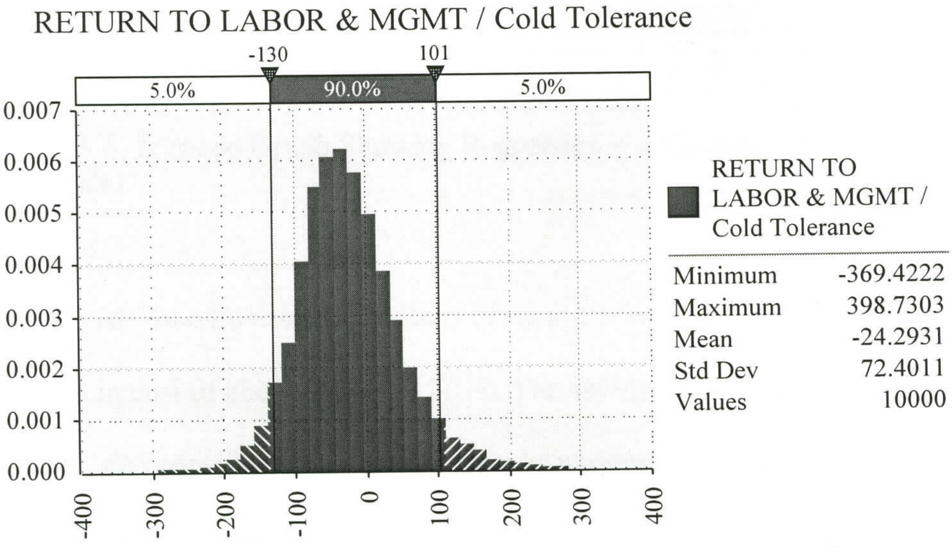


Figure 4.5. Probable Density Distribution for Cold Tolerance in Corn.

Corn: NUE

It has been assumed that the GM trait of NUE helps in savings of up to 10 percent. Rest all variables are treated same as in Base Case. The probability distribution for RTLM in NUE is presented in Figure 4.6.

The RTLM for NUE Tolerance was 90 % of times found to be between -128 to 96, which means that return to labor and management varies between a loss of $128 on the downside up to profit of $96.The variables that affected RTLM most in case of Cold tolerance in corn are presented in Figure 4.7. Yield was found to have maximum positive impact on RTLM in Cold Tolerance (value of .83) followed by Price (.50).

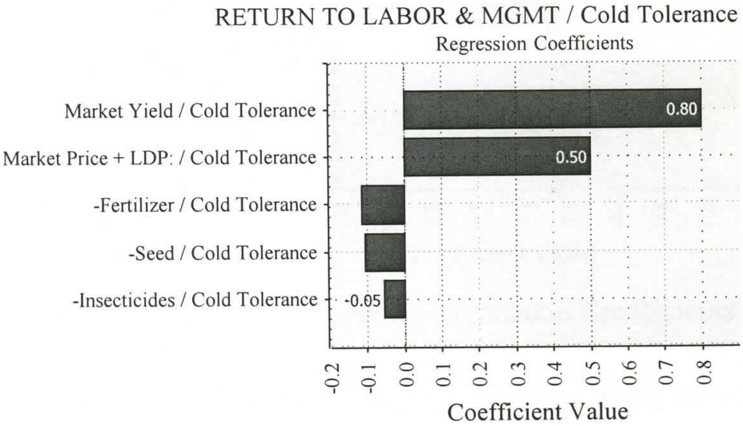


Figure 4.6. Tornado Graph Showing Regression Coefficients for RTLM in Corn (Cold Tolerance).

Corn: 'All'

'All' in corn assumes savings of up to 25 % owing to drought tolerance and saving of 10 % in cost of chemicals as in NUE. The saving of 5 % from cold tolerance GM trait has not been considered as it would have been over and above the saving of 10 % loss from drought. Also it is not known if drought and cold tolerance would lead to 10 + 5 % savings

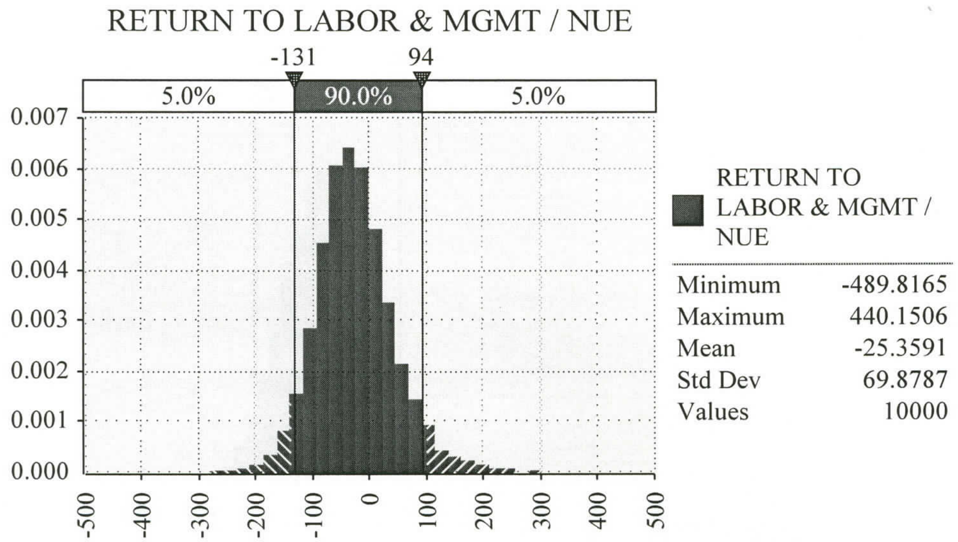


Figure 4.7. Probable Density Distribution for NUE in Corn.

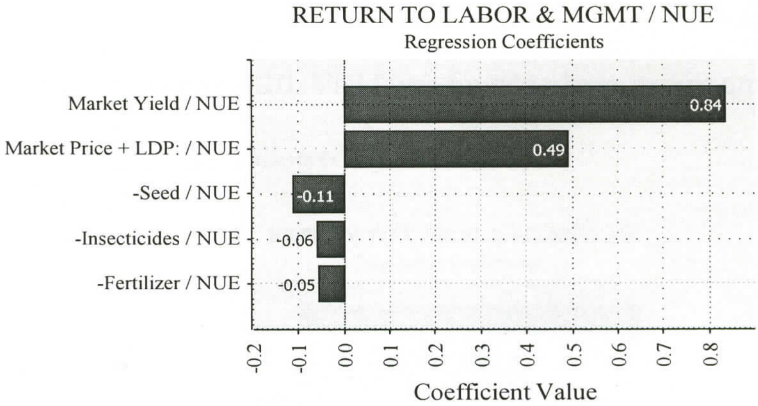


Figure 4.8. Tornado Graph Showing Regression Coefficients for RTLM in Corn (NUE).

or any other case, thus maximum of these two (10 %) have been used. Rest all variables are treated same as in Base Case. The probability distribution for RTLM in 'All' is presented in Figure 4.9.

The RTLM for 'All' Tolerance was 90% of times found to be between -130 to 96, which means that return to labor and management varies between a loss of $130 on the downside up to profit of $96.

The variables that affected RTLM most in case of Cold tolerance in corn are

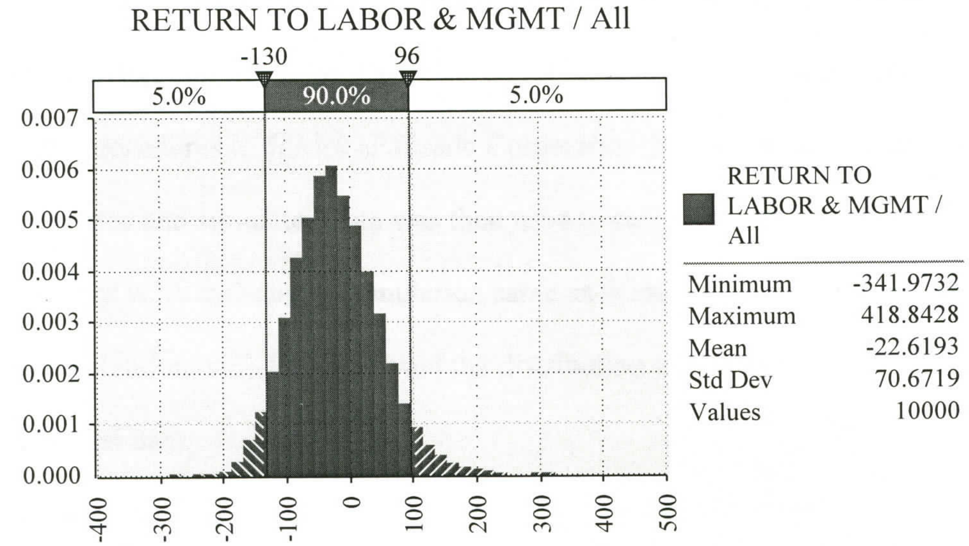


Figure 4.9. Probable Density Distribution for 'All' in Corn.

presented in Figure 4.10. Yield was found to have maximum positive impact on RTLM in 'All' (value of .82) followed by Price (.52).

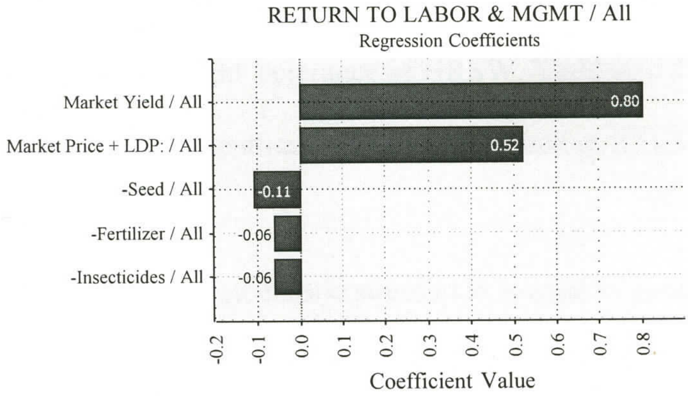


Figure 4.10. Tornado Graph Showing Regression Coefficients for RTLM in Corn ('All').

Derivation of Risk Premiums

The risk premiums that a farmer or a decision maker with different risk preference would be willing to pay for GM trait(s) are calculated as a starting point. To calculate risk premium stochastic simulation and stochastic dominance procedures are used. The model uses simple budget format where in return to labor and management (RTLM) is assessed while treating some variables as random (Appendix A). The variables treated as random are Yield, Price, costs of Seed, Chemicals, and Fertilizers. These were simulated using Monte Carlo procedures in @Risk (Palisade Corporation 2008). Ten thousand iterations were conducted and simulated data was then used to calculate certainty equivalent. Correlated variables were included in simulation same as those found in historical budgetary data for crops. Random variables followed the distribution as suggested by fit distribution of historical data.

Method: Budgetary Data

First RTLM was calculated from each simulation for Base case and four alternatives: Drought Tolerance, Cold Tolerance, Nitrogen Use Efficiency, and All. The base case was historical data representing conventional crop with no GM trait. Other alternatives allow variation in random variables as per the characteristics of the traits. For example in Drought Tolerance of HRSW, Yield was allowed to have twenty % more yield compared to conventional variety thus affecting RTLM. RTLM is defined as revenue minus costs.

Secondly, stochastic simulation is used to iterate RTLM for each outcome of alternatives. Thirdly, stochastic dominance techniques (described below) are used to analyze and create rankings of preferences for various alternatives across a range of absolute risk aversion coefficient (ARAC). Lastly, SERF is conducted to estimate the certainty equivalents that farmer or a decision maker would put on a risky alternative relative to a no-risk investment. Certainty equivalents calculated across range of ARACs are used to rank alternatives and determine where and how the preferences amongst alternatives (base case and GM traits) change thereby resulting in different risk premiums for various alternatives of GM trait(s) relative to base case.

From SERF perspective, the decision maker has five alternatives including the base case (no GM trait). Other four alternatives are Drought, Cold, NUE, and "All" (drought, cold, and NUE combined in to one). The model measures risk associated with choice of growing GM crops relative to conventional crop as perceived by grower. The distribution of RTLM is then evaluated using SERF which builds on other studies namely by (Ribera, et al., 2004; Sangtaek, et al, 2005).

Method: SERF & Stochastic Dominance

Taking reference from the subjective research done on various traits in pipeline that are of interest to us and the claims being made by various public and private organizations/companies, the variables were allowed to vary over a certain range of distribution to arrive at resulting distribution of 'RTLM'. The change in variables was done as per the distribution of respective variables in the past through method of best fit in @risk. After getting a certain best fit distribution for a variable, the variable was allowed to change in same manner while simulating five thousand iterations for distribution of change in RTLM. The simulation data was used to calculate 'SERF' under a negative exponential utility function and thereafter to calculate 'negative exponential utility weighted risk premiums relative to the base case (simetar). The base case is that of a conventional crop which has no effect due to GM traits under consideration and all other cases have been compared to this case. The difference in RTLM in conventional and GM crop farming gives the starting point for the value of GM trait. Specifically, the Negative Exponential Utility Weighted Risk Premiums Relative to Base Case is the amount of money that a risk neutral farmer would be willing to pay for possessing the GM trait in the crop. Later on, risk averseness of farmers have also been calculated, based on simulated data and the risk premiums for the range of risk averse coefficient were calculated.

As in conventional crops, the GM cultivation will involve similar set of input costs and the expected market price for the produce. The crop budget of GM would however differ from that of conventional crop budget in some ways. Some of those differences would need less types and quantity of fertilizers. Similar things can be said about herbicides.

No segregation costs have been assumed to be included for conventional and GM varieties. Except for the variables under consideration, all other variables for conventional and GM crops have been assumed to be the same like insurance, repair, and all other indirect and direct listed costs. This has been done in order to be able to compare the effect of GM trait on RTLM for various cases with base case.

Input variables are assumed to vary as per the distribution based on historical data and their range was adjusted to reflect the expected effects of GM traits in pipeline. For example, in case of hypothetical GM wheat in North Dakota, it has been assumed that the variety would yield 20 % more than conventional wheat variety under drought conditions while yielding same under normal years. This is has been done in reference to the University of Queensland, Australia (US Wheat Associates, June, 2008), which has publicly released GM Wheat for experimental trials, though not yet for human consumption. The difference in return per acre would help farmer cope better under drought conditions and hence reduces the uncertainty in yield. This reduction in uncertainty is what farmer would be willing to pay the premium for. The same premium is the proxy for technology fee that a company would be planning to charge from the farmer. Normally as per discussion from various sources, and Dr. William Wilson, the companies charge approximately 50% of the potential premium from the trait benefit. There for the sake of our model in part 2, the technology fee has been taken as half of negative exponential utility weighted risk premiums calculated in part 1 of this paper. This value of trait has been compared with the values of technology fees that have been used by previous studies to adjudge its relevance.

SERF is conducted to estimate the certainty equivalents that decision makers would place on a risky alternative relative to a no risk investment. Certainty equivalents are estimated across a range of risk aversion coefficients and used to rank alternatives and determine where preferences among alternatives change and to estimate the risk premium for Base case (no trait), Drought tolerance, Cold Tolerance, NUE, and All Traits (all traits combined into one as a stacked trait).

SERF was used to rank risky choices based on certainty equivalents assuming a negative exponential (CARA) utility function for a range of ARACs (Hardarker, et al., 2004). For different ARAC, certainty equivalents were estimated and ranks compared. The levels of risk aversion were identified where preferences changed. The advantage of certainty equivalents is that "the absolute differences in the CE values between risky alternatives represent the risk premium that decision makers place on the preferred alternative over another alternative" (Ribera, et al., 2004). Premiums provide perspective on the magnitude of differences in relative preferences among choices. The premium indicates the change that would have to occur in the certainty equivalent of net payoffs in order to induce a change in preferences. The sign of premiums indicates the preference relative to the Base Case with no GM traits. Positive premiums indicate the alternative (GM trait(s) is preferred to Base Case, while negative premiums indicate the reverse.

The range of ARAC utilized was from 0.00 to 0.15 for both the crops (corn and HRSW) where the upper bound was estimated using methods developed by McCarl and Bessler (1989).

To start with putting a price for technology fee for a trait, we started with the price that it would cost to a farmer under various conditions wherein the trait would be helpful. For example, a trait like drought tolerance would play a role when there is a drought and under drought conditions, it can yield 20 % more than the conventional varieties. This would impact the price and yield. For a trait like NUE, it would help in reducing the cost of fertilizer required in comparison with conventional varieties.

Using stochastic simulation, the data was collected for simulation of 10,000 observations of Base case and GM traits for all the crops. Using the data collected from simulation, the values for risk premiums were deduced for various coefficient of risk averseness. For sake of simplicity and practicability of results, only some range of risk averse coefficient was taken into consideration and thus the respective risk premiums that farmer would be willing to pay for a trait. A set of three values of risk premium is taken into account so as to get a distribution of values of a trait, which are then used in Part 2.

Results: Risk Premiums

Corn: Risk Premiums

SERF under negative exponential utility function in corn was conducted in order to arrive at value for the loss of which a farmer would be indifferent. The actual values for

SERF in Corn are presented in Appendix A. The SERF procedures were used to determine the certainty equivalent (Figure 4.11) and risk premiums (Figure 4.12) for each alternative.

Figure 4.11 shows the certainty equivalents for various alternatives for a risk neutral farmer (ARAC=0) and subsequently risk averse farmer (ARAC>0). ARAC of .15 represents farmer with most risk averse attitude (McCarl and Bessler, 1989).

Risk premiums are measured as the difference in certainty equivalents relative to the Base case and all other respective alternatives of Drought, Cold, NUE, and 'All'. The risk premiums are shown in Figure 4.12 across the range of ARACs examined. It can be seen that with increase in risk averse attitude, 'All' is always preferred to other alternatives and drought tolerance is preferred most over all other individual GM traits.

Some of values for risk neutral, slightly risk averse, and moderately risk averse attitude are shown in able 5.15. Complete set of values are presented in Appendix G. A risk neutral farmer would be willing to pay 46 cents for Drought tolerance trait, $4.17 for Cold tolerance, $2.94 for NUE, and $4.88 for 'All'. Clearly, Cold tolerance seems to contribute most and 'All' is preferred maximum b a risk neutral farmer. For slightly risk averse farmer (ARAC=0.0188), NUE is preferred among individual GM traits for risk premium of $17.17, but 'All' is undoubtedly preferred over all other. Moderately risk averse farmer (ARAC= .05) would be willing to pay up to $176.66 for drought tolerance.

HRSW: Risk Premiums

Complete set of values of risk premiums for respective risk averse attitudes are presented in Appendix G. Growers are willing to pay most for 'All' followed by drought tolerance trait. Low risk averse farmers prefer NUE over cold tolerance (Figure 4.13 and Figure 4.14). Perceived value of GM trait increases with risk averseness (initially).

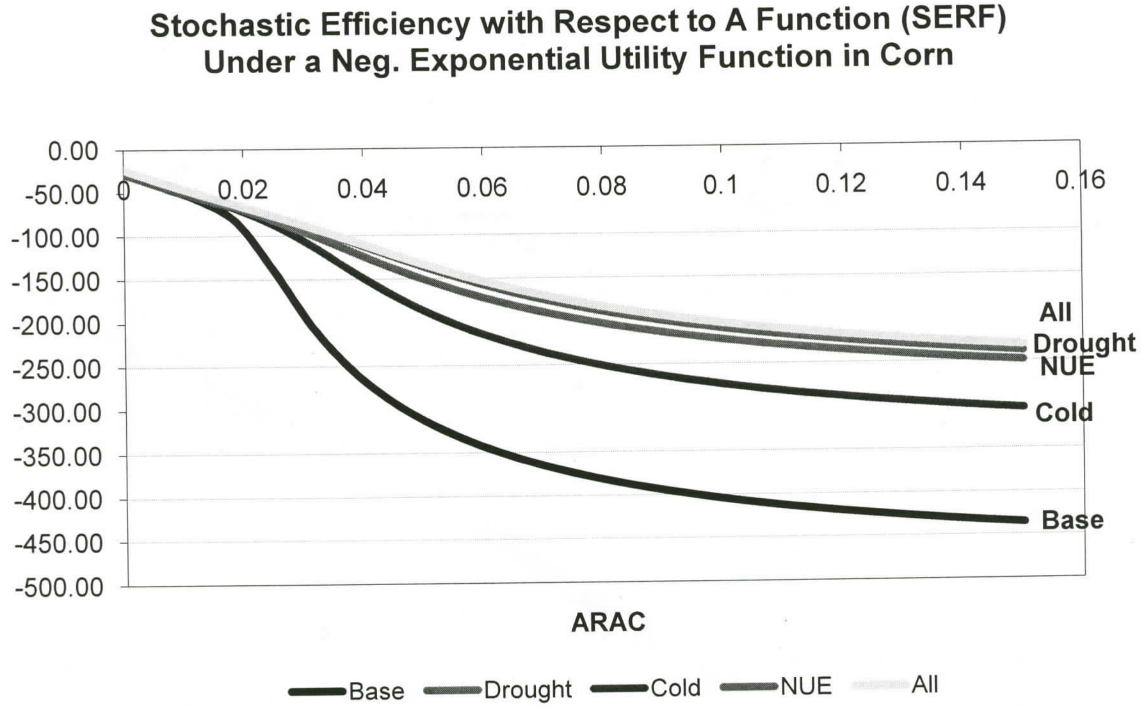


Figure 4.11. SERF in Corn Against ARAC.

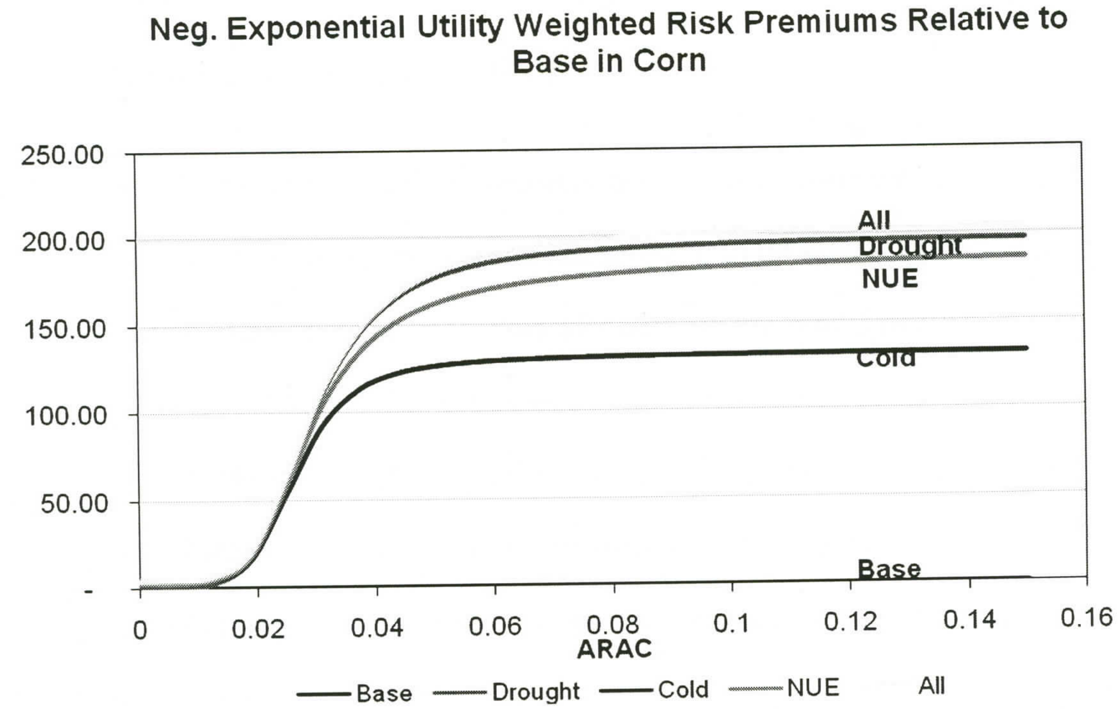


Figure 4.12. Stochastic Efficiency for Alternative Traits for ARACs Considered in Corn.

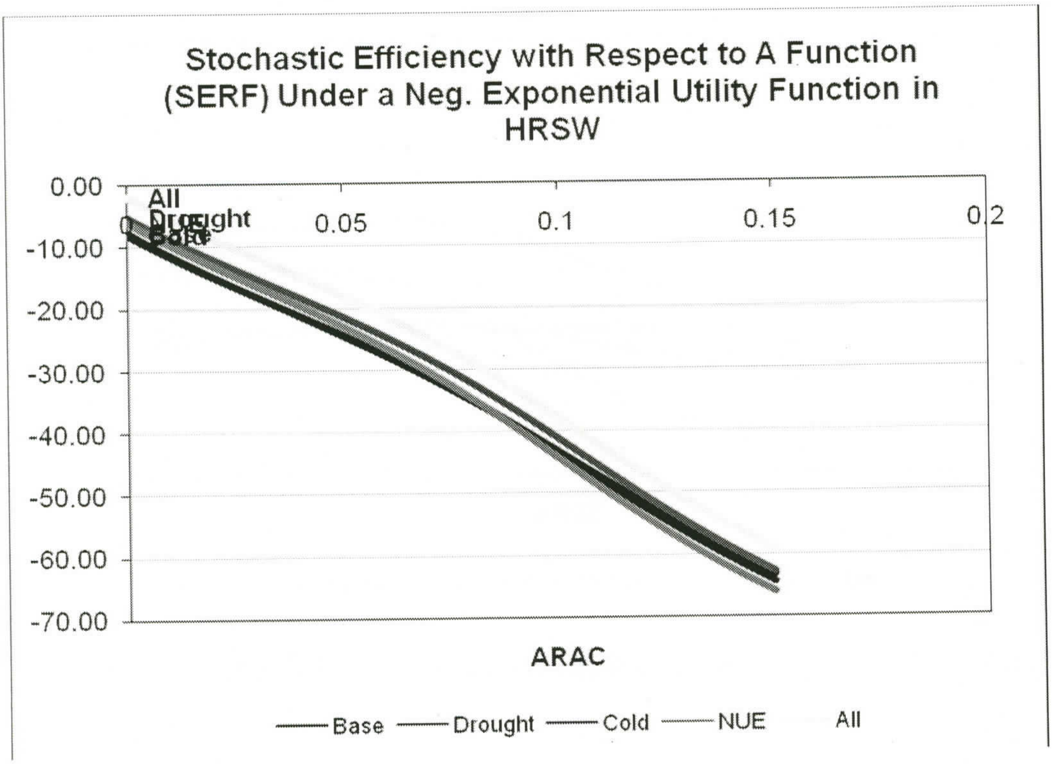


Figure 4.13 SERF in HRSW Against ARAC.

The value of risk premiums give us an idea as to how much a grower with certain risk averse attitude, would perceive the benefit from adopting a GM trait. It does not give us a value of GM trait. Also, if factors other than considered in this model were to change/impact the RTLM, the risk premiums calculated here would differ.

Risk premiums calculated across risk attitudes of farmers for corn, and HRSW are summarized in Table 4.5. These values are later used in part 2 (Chapter 5) as input for potential technology fee for a GM trait developing company as source of revenue to calculate option values.

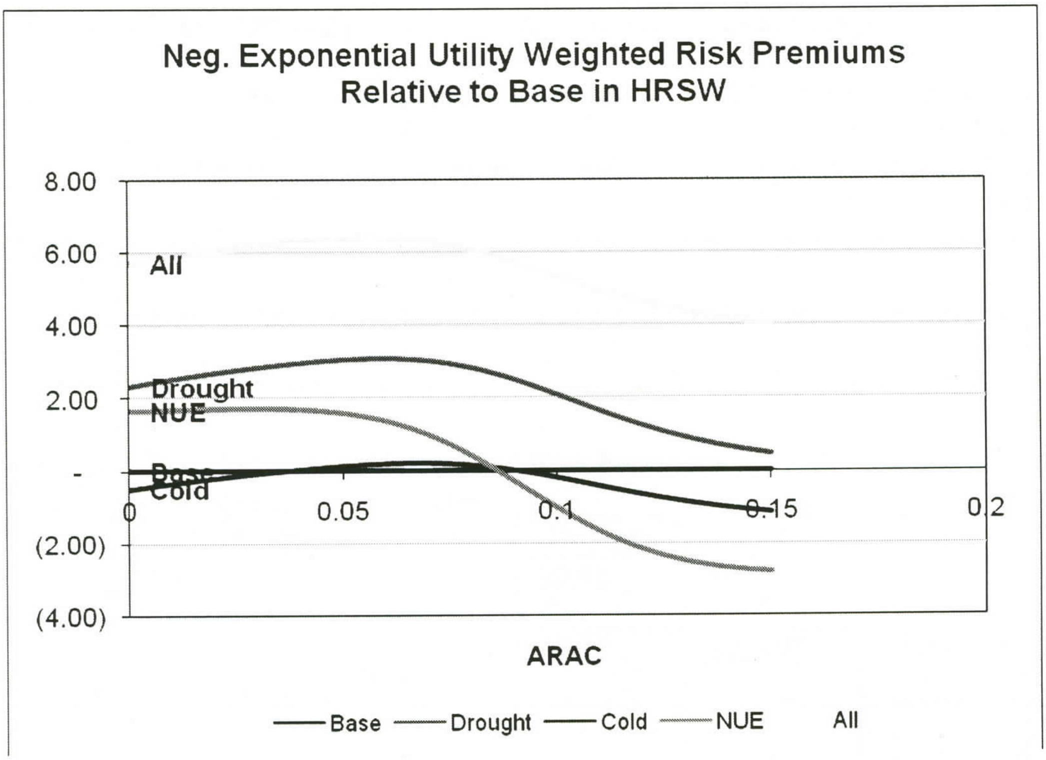


Figure 4.14. Stochastic Efficiency for Alternative Traits for ARACs Considered in HRSW.

The variation of risk premium for any one alternative also means that farmers view that value of trait differently. Alternatively, a seed company can charge different prices from different farmers (say in different geographical region) depending on the representative risk averseness of majority of farmers. The risk premiums for risk neutral, slightly risk averse, and moderately risk averse attitude farmers are used as proxy for technology fee (in part II) as a source of revenue for a biotech company. The wider range of technology is warranted due to other published reports according to which benefits to growers may range from \$15-\$115/ha (*GM Drought Tolerant Wheat Wait*, Farm Weekly, Australia, April 1, 2009).

Part 2 (Chapter 5) uses the distribution of values for the risk premiums that farmer would be willing to pay for a trait(s) for each crop. This risk premium can be taken as proxy that a company can possibly charge from farmer. Since, subjectively, we decided that since a company would normally charge less than 60 % of maximum possible price that it can charge from farmer, we chose the values for risk premiums only for lower ARACs (in Part1). Using the distribution of the price that a company would earn from each farmer (technology fee), variables like planted acres and adoption rate were used to arrive at NPV of FER. The NPV is then used in 'real option tree' for a series of combination of possible scenarios. Out of five stages of development, at every stage, the management has three choices of options like to 'continue', 'wait', and 'abandon'. Option to 'continue' refers to the decision by company management to move onto next stage of development. Option to 'wait' means that company chooses not to move onto next stage of development leading to less value of option as it essentially means more time for a particular stage of development. Option to 'abandon' refers to the salvage value that a company can get by

Table 4.4. Risk Averse Coefficients and Risk Premiums for Risk Neutral, Slightly Risk Averse, and Moderately Risk Averse.

	ARAC	Base	Drought	Cold	NUE	ALL
Corn	0.0	Risk Neutral	$0.46	$4.17	$2.94	$4.88
HRSW	0.0		$2.32	$(0.49)	$1.66	$5.71
Corn	0.0188	Slightly Risk Averse	$16.54	$15.59	$17.17	$20.15
HRSW	0.0188		$2.66	$(0.20)	$1.71	$6.04
Corn	0.05	Moderately Risk Averse	$176.66	$126.11	$162.01	$179.57
HRSW	0.05		$3.04	$0.15	$1.60	$6.40

abandoning the further development of trait by either using the knowledge gained for other research or licensing the trait to someone else. The salvage value has been assumed to be 35% of investment in this paper to make it comparable to previous study by *Flagg, Wilson 2007.* Binomial Option model was used to model the possible combinations of options at each stage of development.

TRAIT OPTION MODEL: METHODS AND RESULTS

Introduction

Developing a GM trait involves risk and uncertainty in terms of investment, time, and returns. Therefore it becomes imperative for policy makers establish guidelines that attract investment in trait development that are expected to be of benefit for the public in large. The same is true for a firm management that has to decide whether to invest in such projects or not. They also face the dilemma of making decisions about whether the trait is worth commercializing or if they would be better off by selling the trait during the development stage to some other company in similar business. This thesis thus uses the Real Option methodology to evaluate GM traits as Option values at various stages of development. The approach helps managers decide as to what is best possible option in case he makes certain decision today. It is also helpful in comparing different pathways (series of decisions) and thus better exploit the potential cash return in future from investment made today.

The overall problem of valuing and pricing of a GM trait is modeled in two steps. Part one deals with putting a value to a trait (Risk Premium, using SERF) from a farmer's side which is presented in Chapter 4. Part two deals with using this value of trait as technology fee to model the various stages of development of trait (using Real Options) for a company's management. Results from part one are thus inputs for Part two, the methods and results of which are presented in this chapter.

Real Option Methodology

GM technology is an irreversible investment involving stepwise process spread over a cumulative time period of 8 to 10 years. Each phase has different probability of success. Management has the opportunity after completion of a particular phase for making decision about investing in the following phase. For sake of simplicity, it is assumed that uncertainty associated with fixed cash flows is resolved at completion of each phase and decision to invest is taken before the start of subsequent phase. To better understand the uncertainty and the inherent opportunity available to management, the overall process from identification of a potential economical GM trait, till the time it is commercialized, can be broadly categorized into five development phases as following:

I. Discovery
II. Proof of Concept
III. Early Product Development
IV. Advanced Product Development
V. Regulatory

At the end of each phase, management has the option to decide whether to continue, wait or abandon trait development. Every stage involves investment of millions dollars and time span of 1-4 years (Table 5.1). This is consistent with previous study done (Flagg and Wilson, 2007) to maintain the results comparable. Each developmental stage has different probability of being successful.

Three possible options to "continue", "wait", and "abandon" have been modeled in this thesis. Each is actually the 'option value' evaluated in model as defined in binomial option approach. The option to abandon exists at every stage of development. However, out of other two options, only one of the two can be chosen. This has been done to use same single period probability while calculating option value at any particular stage. Only cumulative probabilities (for the stages considered) are known. Thus in order to use the published probabilities and to make the results comparable with previous studies, binary option model approach is used.

Table 5.1. Typical Time and Investment Required for Developmental Stages of a GM Trait.

Trait Development Assumptions in Real Option Model (Corn and HRSW) Showing Random Parameters/Distributions.					
	Discovery	Proof of Concept	Early Development	Advanced Development	Regulatory Submission
Time (in Years)	=Uniform(2, 4)	=Uniform(1, 2)	=Uniform(1, 2)	=Uniform(1, 2)	=Uniform(1, 3)
Investment	=Uniform(2M, 5M)	=Uniform(5M, 10M)	=Uniform(10M, 15M)	=Uniform(15M, 30M)	=Uniform(20M, 40M)
Cumulative Probability	0.05	0.25	0.50	0.75	0.90
Single Period Probability	0.20	0.50	0.67	0.83	0.90

Source: Monsanto 2009, Flagg Ian and Wilson 2008, Jagle (1999)

Other option trees evaluate only option to continue and option to wait, and during subsequent nodes in that tree thereafter. The option to abandon is assumed to be same as plotted in first option tree. This has been done to use same single period probability while calculating option value at any particular stage. Thus in order to use the published probabilities and to make the results comparable with previous studies, the binary option model approach is used.

Types of Option

This thesis models three options: “continue”, “wait”, and “abandon” using binomial option model. The ‘continue’ growth option represents the decision of management to continue to the next stage and make further investment. Management would make such decision in case it is in-the-money. In case management chooses to wait it would not make any further investment for the period of next (hypothetical but similar to the one in case it had continued) stage. Thus, the option to ‘wait’ for any stage is valued same as option to ‘continue’ of previous stage with additional time frame added to it without investment of subsequent stage. The option to '<u>abandon</u>' evaluates the salvage value of the investments made. The simplest binomial option tree would be the one involving option to 'continue' and 'abandon'. For example, in case of drought tolerance, the simplest case where in the management decides to continue at the end each development phase, the option value at the Regulatory phase is shown in Table 5.2. Other possible pathways are plotted in reference to this tree. More details are presented in "Results" later on and in Appendix B. The risk mean values from stochastic simulation of salvage values are shown in Appendix A.

Subsequently, the option to 'wait is modeled with option to 'continue' which is also the starting point of a new option tree (shown in appendix). This is done because of lack of any published data regarding the decisions in the past about how many times the decisions were made to proceed with investment, defer it or abandon the research project. Only risk neutral probabilities of an option value going up or down (as required in binomial option) were calculated from cumulative probabilities of a trait progressing to next development stage from annual report (2008) of Monsanto^{R}.

Valuation of options is helpful for management in better comparing and analyzing the possible scenarios. The possible scenarios indicate the variation in option value of traits at different stages of development had they made the choice to 'continue', 'wait' or 'abandon'. For example, if the management perceives that the difference in option values of 'continue' and 'wait' is worth enough considering political and social environment, then option to 'wait' will be a rational choice. Appendix B shows many such choices that can be made by management and how the option value of GM trait varies with every choice made. The real option methodology captures the risk associated with each stage of development and takes into account the different choices available to management at the end of each stage. The DCF methodology fails to consider that management may chose to wait at the end of any stage and thus a constant expected future cash flow is not a valid case. If management decides to defer the investment at the end of any stage and then continue, it implies that the trait is at same stage as previously, but in terms of time it has elapsed to next stage. For sake of simplicity, if management chooses to wait, then the time of wait are equal to the time of next stage of development had it chosen to continue. This helps in drawing out possible pathways that management can follow by making different choices at the end of each stage on a parallel basis. The possible cases are presented in Appendix B in reference to an ideal case where management decides to continue at all the stages. If management decides to 'wait', a new option tree starts and progresses as simple binomial option model. The new tree evaluates only option values for 'continue' and 'wait'. Comparisons can thus be made by looking at option values at nodes of various possible pathways.

Choices made by management affect the FER and thus the NPV. A constant rate of discounting the future cash flow is not appropriate and representative of actual possible choices available to management. The option value of a GM trait as calculated in this thesis at each stage of development captures the risk of GM trait moving onto the next stage and the gain that particular trait is expected to provide to the farmer. This is so because the option value depends on probability of success, time taken for the stage, investment made in the stage, adoption rate, and technology fees.

The adoption rate and technology fees affect the NPV of FER and are one of the most critical random variables as found in model results. Each of these are defined in separate sections below.

Table.5.2. Option Tree for Corn, and HRSW Showing One of Possible Pathways for Drought Tolerance Representing "Continue" at Each Node. At Each Node, Firm Chooses to "Continue". (1=Continue, 2=Wait, 3=Abandon).

	Discovery			**Proof of Concept**			**Early Development**			**Advanced Development**			**Regulatory Submission**		
Corn	1	Continue	105M	11	Continue	631M	111	Continue	1386M	1111	Continue	2280M	11111	Continue	3009M
	3	Abandon	1.25M	13	Abandon	3.81M	113	Abandon	7.8 M	1113	Abandon	15.12M	11113	Abandon	24.31M
HRSW	1	Continue	(3.40)M	11	Continue	(15.20)M	111	Continue	(24.69)M	1111	Continue	(27.53)M	11111	Continue	(11.46)M
	3	Abandon	1.25M	13	Abandon	3.81M	113	Abandon	7.8 M	1113	Abandon	15.12M	11113	Abandon	24.31M

Model Details

The model used is an extension of Jagle (1999), which developed a real options model for "new product development" case study and Flagg and Wilson, 2007.

First the NPV of FER is calculated from technology fees (TF, random variable), planted acres (PA), and projected adoption rate (PAR, random variable). Total FER for 15 years after commercialization of trait is calculated as:

$$\sum_{i=0}^{n} \text{FERi} = c * \text{TFi} * \text{PAi} * \text{PARi} * (1/(1+\text{I})^\wedge \text{Ti})$$

Where:

c= Ratio of potential technology fee a company aims to charge

TF= Technology fee charged (for $i^{th\ year}$) by company in \$/acre

PA=Planted acres (for $i^{th\ year}$) for the crop

PAR=Projected adoption rate (for $i^{th\ year}$)

I=Weight adjusted cost of capital ((WACC) = 10 %)

T= Time elapsed after trait is commercialized

i= the year after commercialization

Also, from industry trends, it is observed that biotech and chemical companies aim to charge a portion of potential technology fees "c". In base case this ratio is assumed to be 50 %. The risk premiums for a risk neutral, slightly risk averse, and moderately risk averse farmer are treated as proxy for minimum, most likely, and maximum technology fee values are used to derive the distributions (Table 5.3).

The FER for 15 years after commercialization is then used to calculate nodal values of binomial option tree using backward induction. In the binomial option tree, the time of development and investment cost are treated as random. Each phase has a probability that GM trait would successfully proceed to next phase. This cumulative probability is assumed from Monsanto^{R}'s annual report 2008. Cumulative probabilities converted into single period probabilities are then treated as risk neutral probabilities for option value of GM trait at each node (development phase). The risk neutral probability for any node is solved as:

$$P = \frac{((1+r)^{t}) * S - S_{-}}{(S_{+} - S_{-})}$$

Where:

P= risk neutral probability

r= risk free interest rate

t= time in the phase of development

S= current value of project

S_{+}=Present value of cash flow at the end of phase, in case of upward movement

S_{-}=Present value of cash flow at the end of phase, in case of downward movement.

Planted Acres

The planted acreage for Corn and HRSW is from national planted area for the US (ERS, USDA.gov accessed May 2009). Although, the farm budgetary data is from state, the option model uses the national acreage because any biotech company would not research GM trait(s) for a small land area as of a state. In sensitivities, the acreage of Canada for HRSW is also used to evaluate the effect of increased planted acreage for these crops on option values.

Adoption Rate

The adoption rate is allowed to vary within minimum, most likely, and maximum, the values of which were subjectively decided keeping in mind the current trend reflected globally for GM traits (International Service for the Acquisition of Agri-Biotech Applications, ISAA.org) , previous studies (Flagg, et al., 2008), and current industry trends. PAR uses a triangular distribution with additional gain in case of consecutive years of drought (Figure 5.1, details in sensitivities).

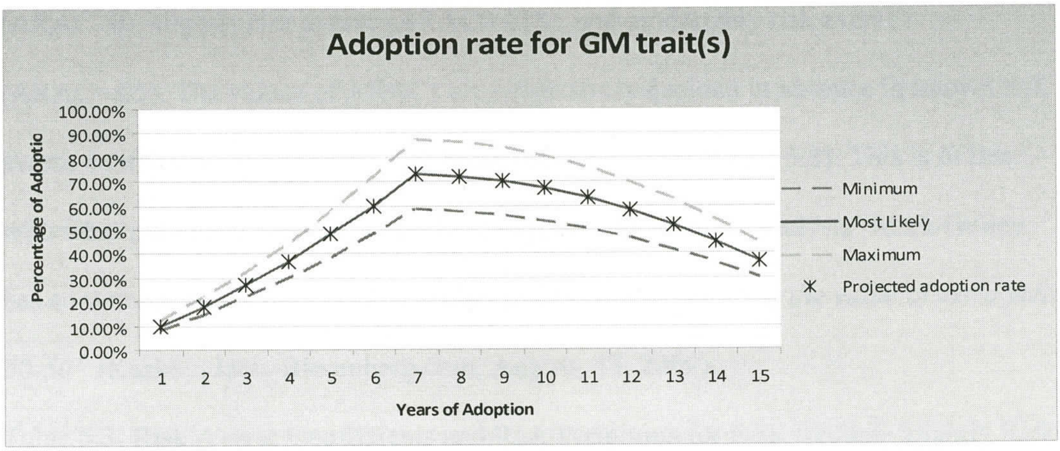


Figure 5.1. Projected Adoption Rate (PAR) of GM Traits for Fifteen Years After Commercialization.

Adoption of 'drought tolerance' would be insignificant unless there are consecutive years of drought. In order to incorporate this in model, the projected adoption rate is correlated with drought occurrence of previous year. In case of drought in previous year, the random draw of adoption rate would tend to be towards maximum, else, towards lower half of distribution. The average probability of occurrence of drought in 15 years of simulated years after commercialization is 42 % in model. This was decided based on declared drought years during the time frame of data used for calculating risk premiums (Chapter 4).

Technology Fee

Previous studies use various values of technology fee and contend their values to be non-random while disputing the values used by others on the basis of factors like region, soil type, and other savings from agronomic factors. Actual values are not known. Previous studies assume any single value as a source of revenue. This thesis treats technology fee as being derived from farm budget valuations (using SERF methodology), considering the risk mitigation value of trait, and then represents the technology fee as random variable. The distribution is characterized across the prospective risk aversions of growers (ARAC) broadly classified as risk neutral (ARAC=0), slightly risk averse (ARAC=.018), and moderately risk averse (ARAC=.05). The values of ARACs are subjectively decided in absence in known risk averse coefficients representative of prospective adopters (Table 5.3). This is in line with what published news in Bloomberg suggests where in an analysts' Mark Gulley has commented on Monsanto that *"They are in essence splitting the value of extra yield 50-50"* (Kaskey, Jack, Bloomberg.com, August, 13, 2009).

Table 5.3. Risk Averse Coefficients and Risk Premiums for Risk Neutral, Slightly Risk Averse, and Moderately Risk Averse.

	ARAC	Base	Drought	Cold	NUE	ALL
Corn	0.0	Risk Neutral	$0.46	$4.17	$2.94	$4.88
HRSW	0.0		$2.32	$(0.49)	$1.66	$5.71
Corn	0.0188	Slightly Risk Averse	$16.54	$15.59	$17.17	$20.15
HRSW	0.0188		$2.66	$(0.20)	$1.71	$6.04
Corn	0.05	Moderately Risk Averse	$176.66	$126.11	$162.01	$179.57
HRSW	0.05		$3.04	$0.15	$1.60	$6.40

The technology fee represents the value reflected from reduced risk as inferred from risk premiums that farmer would be willing to pay for a GM trait(s). This is calculated using SERF (Chapter 4). Increases in ARACs represent more risk averse attitude of farmer. Values for HRSW are close to values used by previous studies (Berwald, et al.).

The technology fee distribution for corn at moderate ARAC was found to be \$176 which seemed high relative to same ARAC for HRSW. To accommodate for this, technology fee distribution for HRSW follow uniform distribution for risk neutral grower (minimum) and moderately risk averse grower (maximum) (see Figure 5.3 and 5.4). The results of SERF analysis are presented in detail in Chapter4. Here, the risk premium for each crop and trait that were treated as input for real option model, as shown in Table 5.3.

Since the distribution of growers across aversions is not known, we derived three different levels of risk aversion. These are risk neutral, slightly and moderate risk averse. From these we derived triangular distribution of estimated technology fees. These are comprised of a minimum, most likely, maximum value for each crop and trait. Thus, the distribution for drought resistance for corn is {.46, 16.54, 176} which means that the technology fee would be random draw from this distribution (Figure 5.2). It is clear that the value for maximum in corn is greater than previously thought and compared to other traits. It simply means the value of this reducing trait would be large to those growers with moderate risk aversions. Of course, its value would be much less to growers that are less risk averse. HRSW follow uniform distribution where in minimum represents the risk neutral and maximum represents moderately risk averse grower.

The risk premium that a grower would be willing to pay to reduce the uncertainty associated with random events like drought is calculated through certainty equivalents. The risk premiums vary with risk averseness of a farmer. This is taken from Part one of the model presented in Chapter 4. The risk premium is considered as proxy for technology fee that a company expects as its revenue from grower/farmer. This technology fee is then treated as input for Real Option model that makes up second half of the model presented in this chapter.

Salvage Values

The salvage values represent the values that company may get by abandoning the project at any stage of development or by licensing it out to other competitor. Since these values are not known, they have been assumed to be same for each crop in this model and are evaluated only in simplest (first option tree) scenario wherein salvage option values are all the bottom nodes. The distribution for salvage value is taken from (Flagg and Wilson, 2009) to keep results comparative. However, unlike Flagg, et al., 2009, this thesis models three choices for three crops for four traits.

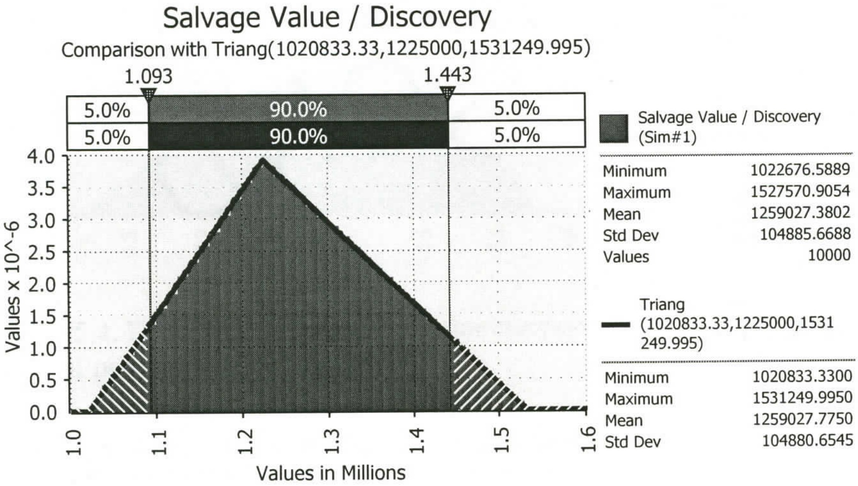


Figure 5.2. Distribution of Salvage Value for Discovery Stage at “c”=.5 (50% of potential technology fee).

Simulation Methodology

The binomial Option tree considers outcomes; option value goes up or down. That is, management may decide to continue or abandon (salvage value). Monte Carlo stochastic simulation is used to model the randomness of variables from @risk by Palisade Corporation^{R}. 10,000 iterations were done for every GM trait modeled (one

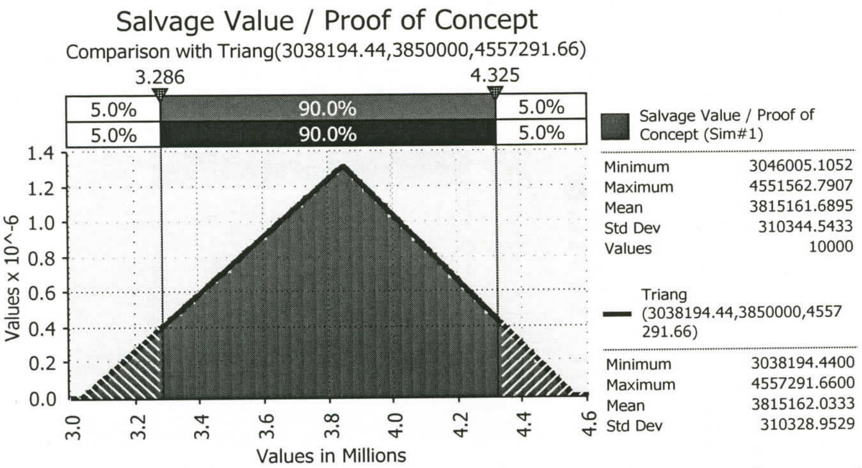


Figure 5.3. Distribution of Salvage Value for Proof of Concept Stage at "c"=.5 (50% of potential technology fee).

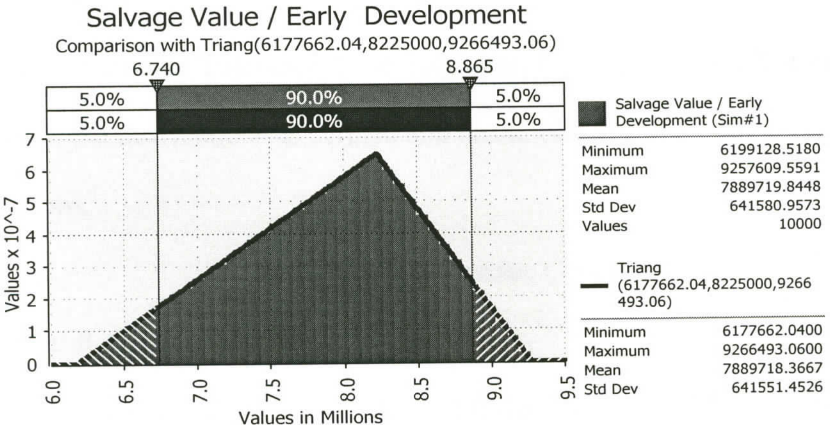


Figure 5.4. Distribution of Salvage Value for Early Development Stage at "c"=.5 (50% of potential technology fee).

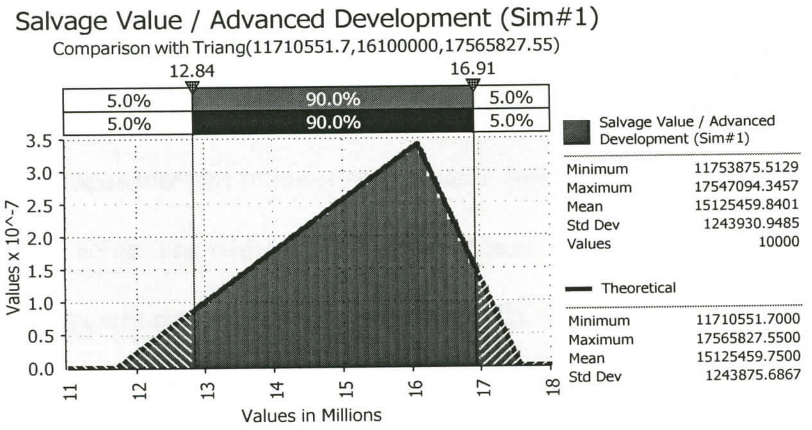


Figure 5.5. Distribution of Salvage Value for Advanced Development Stage at "c"=.5 (50% of potential technology fee).

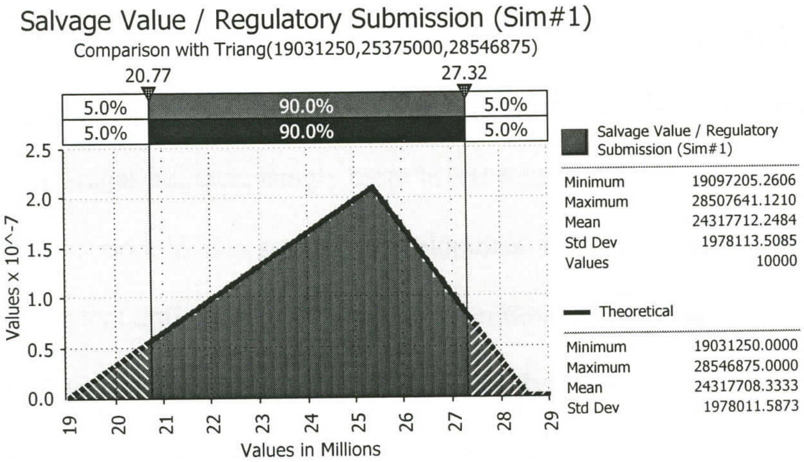


Figure 5.6. Distribution of Salvage Value for Regulatory Submission Stage at “c”=.5 (50% of potential technology fee).

each for Drought Tolerance, Cold Tolerance, NUE, and “All”). The random variables follow the distributions as defined and mentioned elsewhere in this chapter in respective sections.

Results: Corn

Corn: Base Case

Base case assumes that share of technology fee is 50% (c=0.5) and potential acreage of concern is only that of United States. Adoption rate was allowed to vary in simulation as observed historically (Figure 5.1).

On average, among individual traits, drought tolerance is most profitable GM trait likely to be developed by a seed-biotech company as shown in Figure 5.10. Continuous increase in mean option value represents increase in value of in-the-money option value. The widening gap between min, mean, and max with each stage of development represents increased variability with time. Decision maker would therefore be concerned with the gap in mean in-the-money (ITM) option value and minimum in-the-money option value. This also refers to the fact that unfolding of events leads to reduced uncertainty and has value to the management. With the passage of time, the option value for drought tolerance has shown steady increase (Figure 5.7). This suggests that development of drought tolerance in corn is increasingly ITM, less in initial stages but increasingly more in last stages of development. The expected cash return is more in later stages of development. During discovery stage, there is 5 % chance that option value would be 68.5 million or less, whereas in last stage of regulatory submission, there is 5 % chance that option value will be less than $2.05 billion (Figure 5.8 and 5.9).

Drought Tolerance in Corn

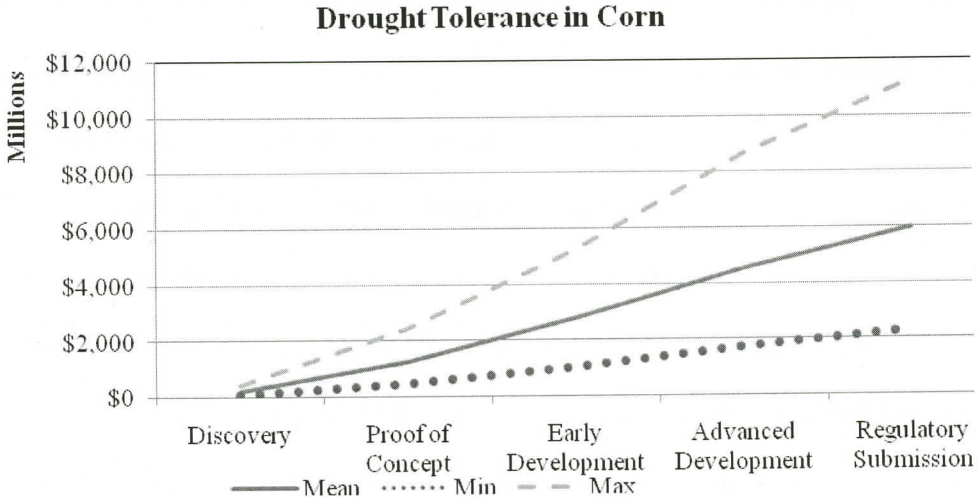


Figure 5.7. Change in Option Values of 'Drought Tolerance' in Corn Across Stages of Development Showing Minimum, Mean, and Maximum for Acreage in United States ($ in millions, c=.5).

The cumulative frequency distribution across traits (Figure 5.10) in last stage of regulatory submission show that stacked trait 'All' provides maximum value at any given probability followed by all individual trait (drought tolerance). The similar figure for drought tolerance across stages of development (Figure 5.11) shows that option value for drought tolerance is more in last stage of development but has more variability in terms of its value (flatter for later stages meaning the later stages of development have more variation) due to increased uncertainty of time and investment and are therefore more risky. However, the risk factor is more than compensated by increased cash return (later stages are continuously to the right of preceding stages). More results for stochastic simulation of other GM traits in Corn are presented in Appendix B through E. At any given probability, the return from option increases with each progressing stage of development.

Among the traits, Drought tolerance has highest value among other individual traits. During the Discovery phase of research, the option value for say drought tolerance is very low (positive value indicates the option is ITM and negative value indicates out-of-money (OTM)). However, later on the option value is found to be significantly high. Had profitability been calculated using discounted cash flow (DCF), there was likelihood of management abandoning the trait development. However, binomial options clearly show that drought tolerance in discovery stage , on an average , is likely to have an option value of $211 Million (Table 1 of Appendix B) with 90 % chance of being more than $105 Million (Figure 5.8 and Figure 1 of Appendix E) but later on increases to $5.9 Billion. Initially there is only 5 % chance of option value being less than $139 million but later on for the same probability, it is $4.09 billion. This clearly reflects the fact the there is more certainty of higher option value at later stages of development due to reduced risk. At regulatory submission, there 90 % chance that option value would be more than $2.0 billion with an average of $3.0 billion (Figure 5.9). In case the management decides to wait, it is treated as starting point of a new binomial tree, wherein the option to wait is equivalent to option to continue of preceding stage of original tree but with additional time of waiting. After waiting time, if management decides to continue, the cost of investment and time of next are taken into account so as to move forward as option to continue. Complete option tree results for other GM traits considered for Corn are presented in Appendix B. Graphs for other developmental stages for each traits are presented in Appendix B through E.

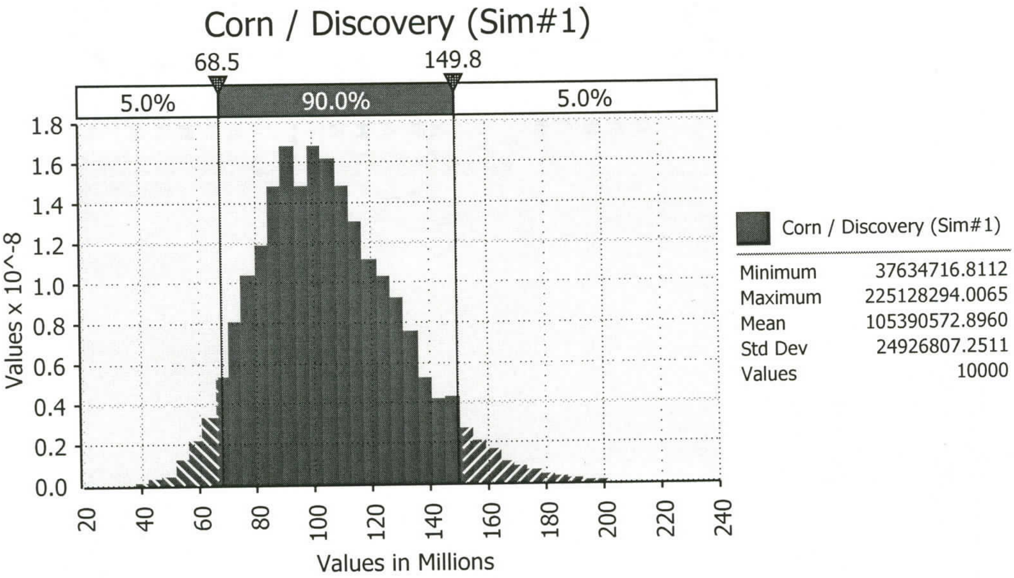


Figure 5.8. Probability Distribution of Option Values for Drought Resistance in Corn in Discovery Phase for Acreage in United States at c=.5.

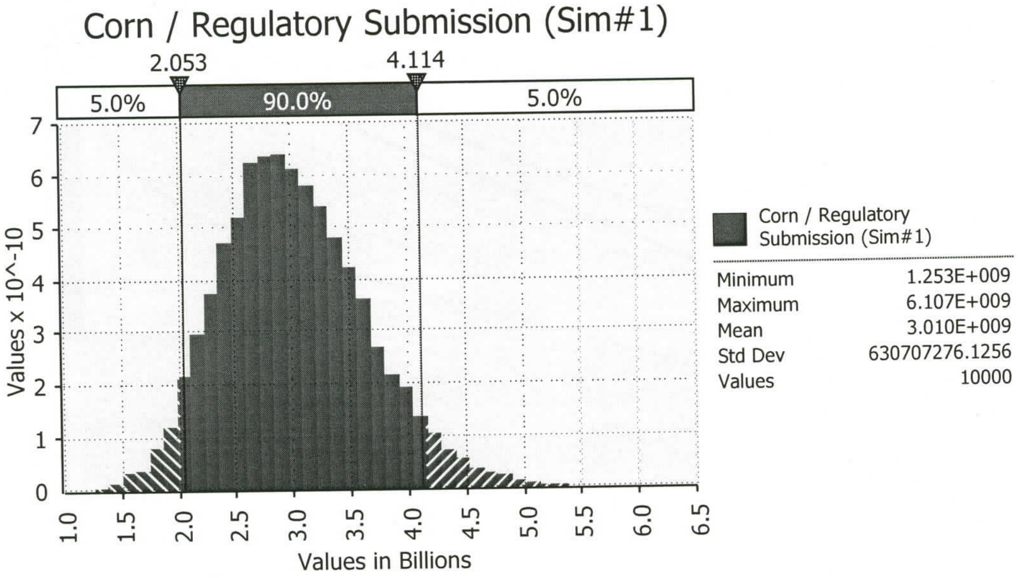


Figure 5.9. Probability Distribution of Option Values for Drought Resistance in Corn in Regulatory Submission Phase for Acreage in United States at c=.5.

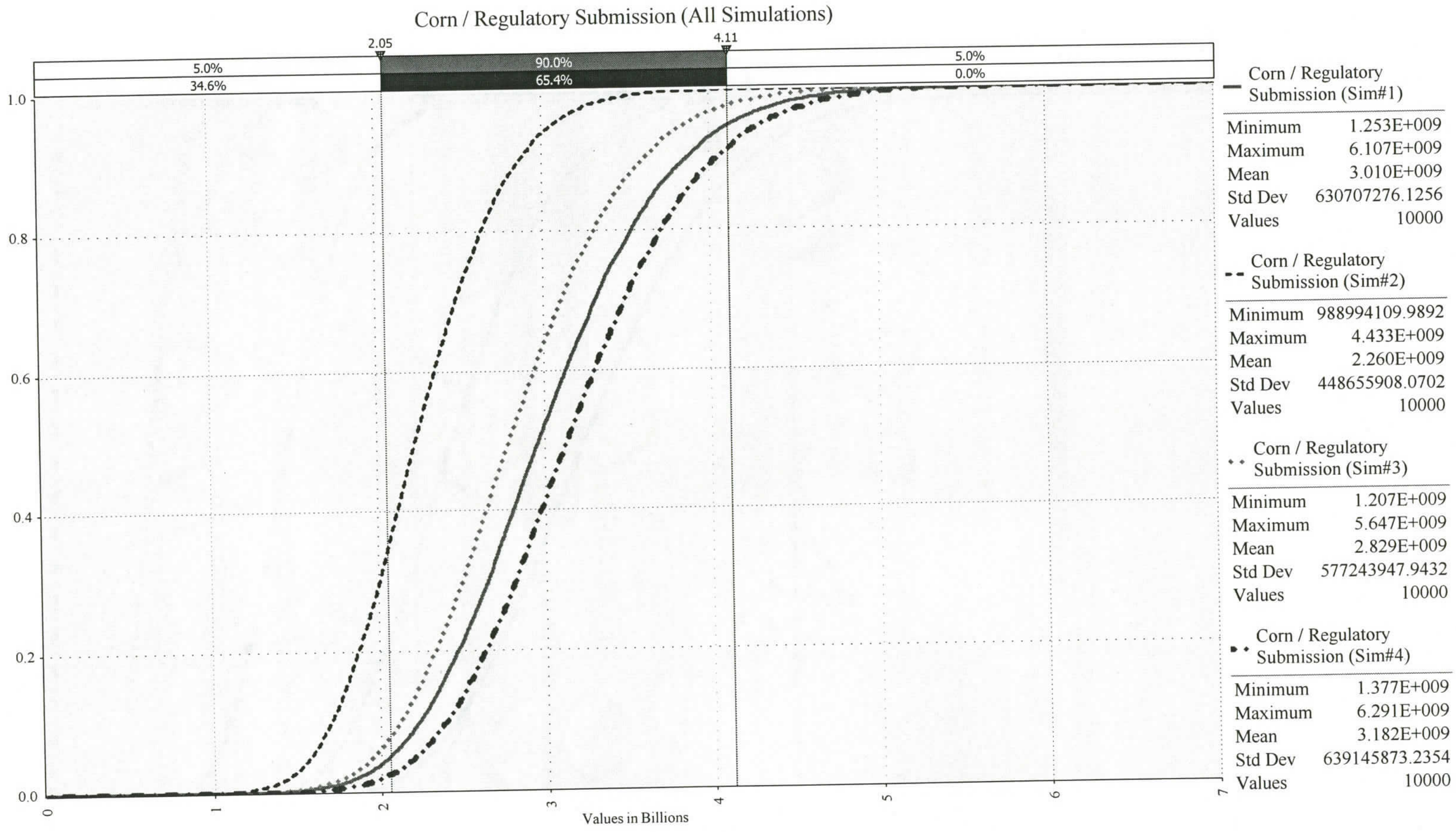


Figure 5.10. Ascending Cumulative Distribution for Option Values Across GM Traits at Regulatory Submission in Corn (Sim #1=Drought, Sim #2=Cold, Sim #3=NUE, Sim #4='All") for Acreage in United States ($ in millions, c=.5).

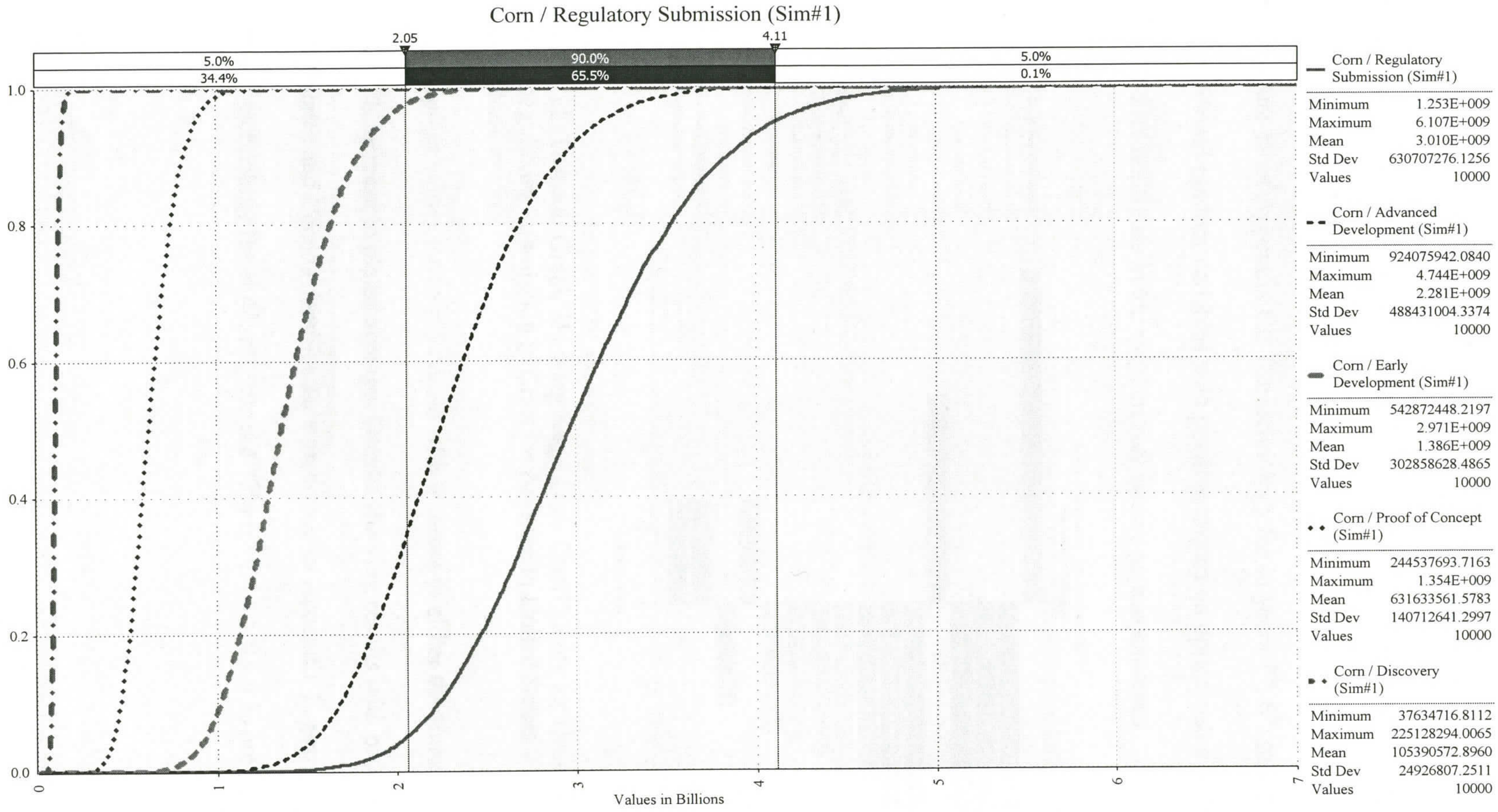


Figure 5.11. Ascending Cumulative Distribution for Option Values Across Stages of Development for Drought Tolerance in Corn for Acreage in United States ($ in billions, c=.5).

Results: Corn: Sensitivities

The most critical random variable on option value is time in regulatory phase which supports previous studies (Flagg and Wilson, 2008) and industry perception. The time taken in regulatory phase has most negative impact on the option value (Figure 5.12, Figure 19 of Appendix C). The technology fee in years 7th, 6th, and 8th are next most important random variables with positive impact on option value of GM trait. Drought does not figure in top most critical factors as was expected.

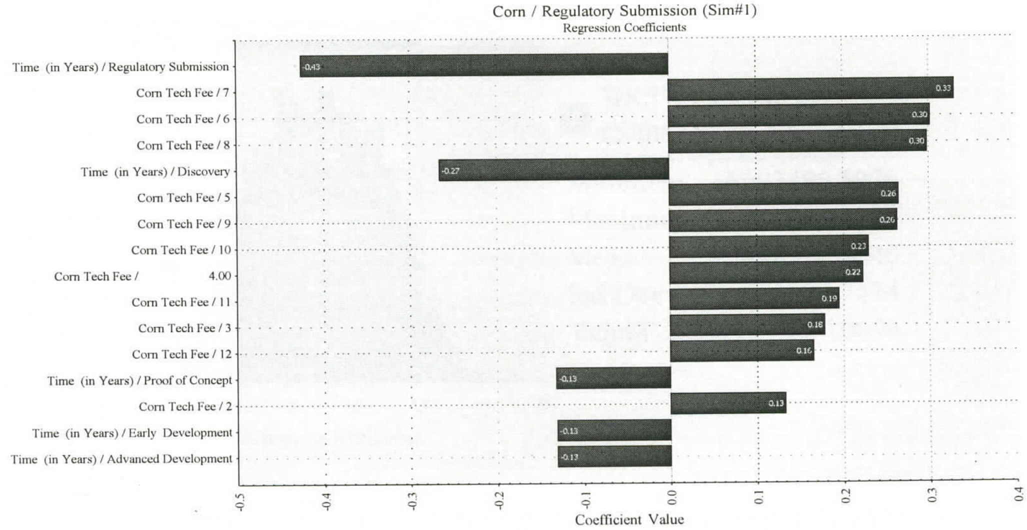


Figure 5.12. Tornado Graph Showing Regression Coefficients for Drought Tolerance During Regulatory Submission in Corn for Acreage in United States ($ in billions, c=.5).

Option values for corn increase with increase in either the share of technology fee or with increase in plated acreage. Graphs showing results with planted acreage of United States and Canada combined are presented in Appendix F. Sensitivity results at shares of technology fee at 40, 50, 60, and 70% (c=0.4,0.5,0.6,0.7) are also presented in Appendix F.

HRSW: Base Case Results

In discovery stage for drought tolerance, there is less than 5 % chance that the option value is out-of money by $5.06 million or more (Figure 5.13) which increases to $21 million (OTM) in last stage, however, there is improvement in mean value (Figure 5.14).

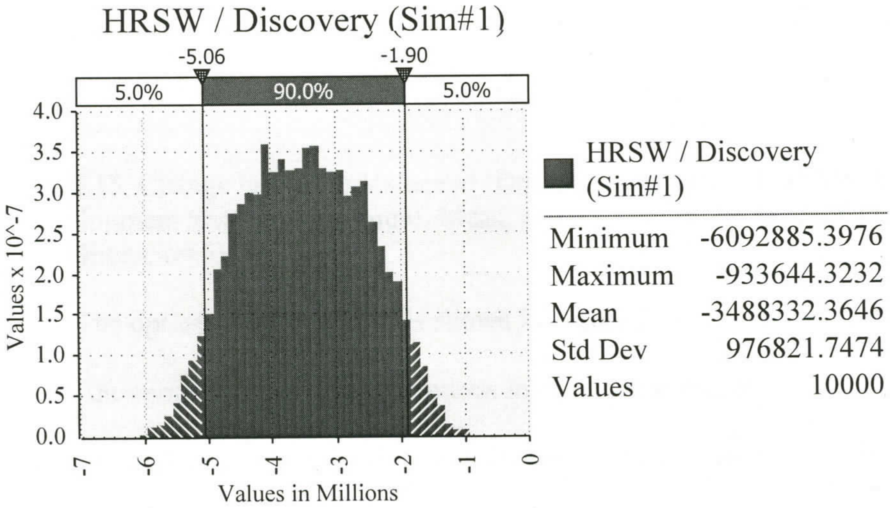


Figure 5.13. Probability Distribution of Option values for Drought Resistance in HRSW in Discovery Phase for Acreage in United States at c=.5.

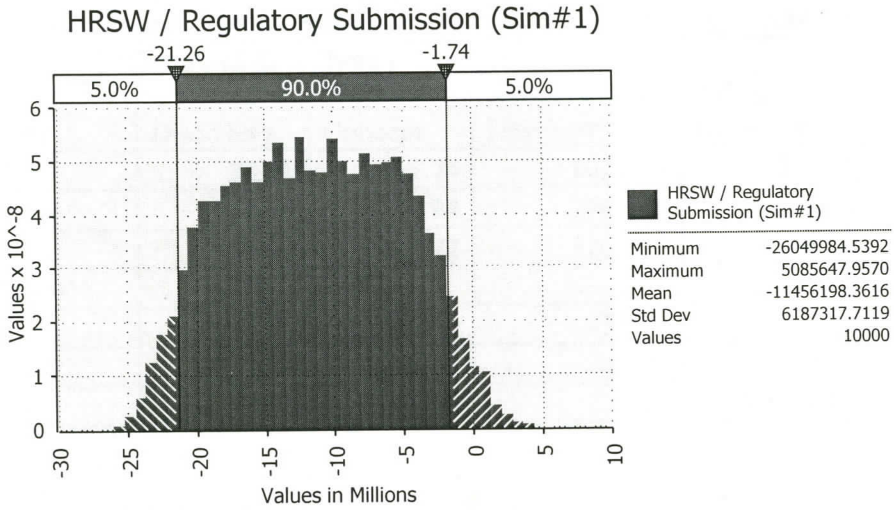


Figure 5.14. Probability Distribution of Option values for Drought Resistance in HRSW in Regulatory Submission Phase for Acreage in United States at c=.5.

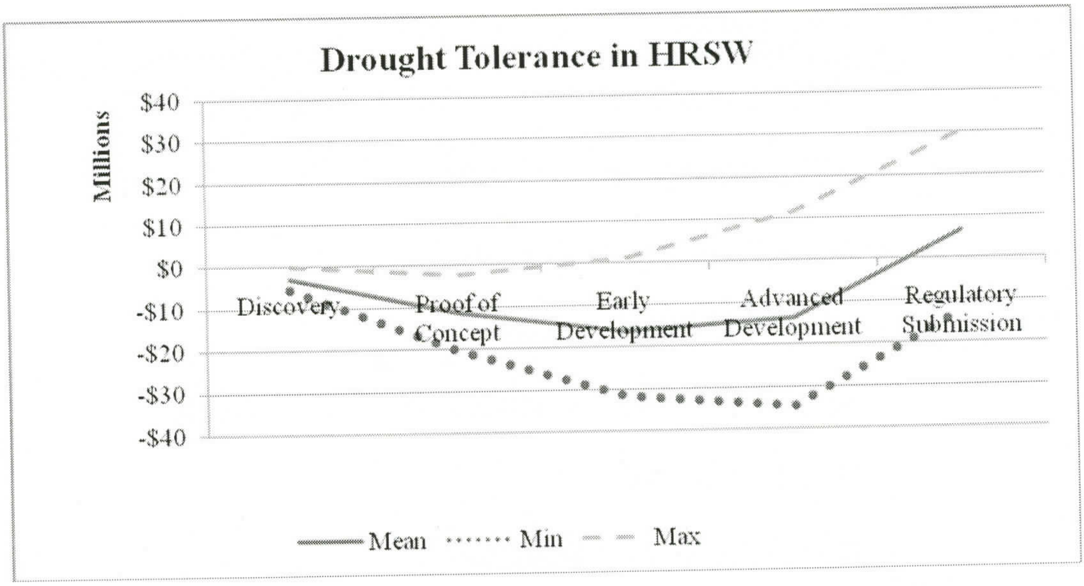


Figure 5.15. Change in Option Values of 'Drought Tolerance' in HRSW Across Stages of Development Showing Minimum, Mean, and Maximum for Acreage in United States ($ in millions, c=.5).

The option tree for HRSW is shown in Figure 5.16. It is found that option value stays in-the-money if there is a continuous investment during all the stages of development. As and when 'wait' option is chosen, it leads to reduction in option value. 'Wait' option is equivalent to management deciding not to invest at that particular time and chooses to postpone the decision of investment at later time.

Table 5.4. Option Tree Showing Minimum, Mean, and Maximum Option Values for Drought Tolerance in Crops for Acreage in United States. ($ in millions, c=.5).

Drought Tolerance ($ in millions)					
Corn	Discovery	Proof of Concept	Early Development	Advanced Development	Regulatory Submission
Min	75.21	465.74	1024.00	1725.44	2298.74
Mean	211.99	1264.94	2767.88	4541.03	5967.82
Max	425.22	2422.72	5260.70	8661.54	11241.47
HRSW					
Min	-5.67	-20.44	-31.72	-34.61	-12.61
Mean	-2.84	-11.33	-16.27	-13.74	6.59
Max	-0.01	-2.46	0.97	11.43	30.28

Results for other traits Cold Tolerance, NUE, and Stacked traits are presented in appendixes.

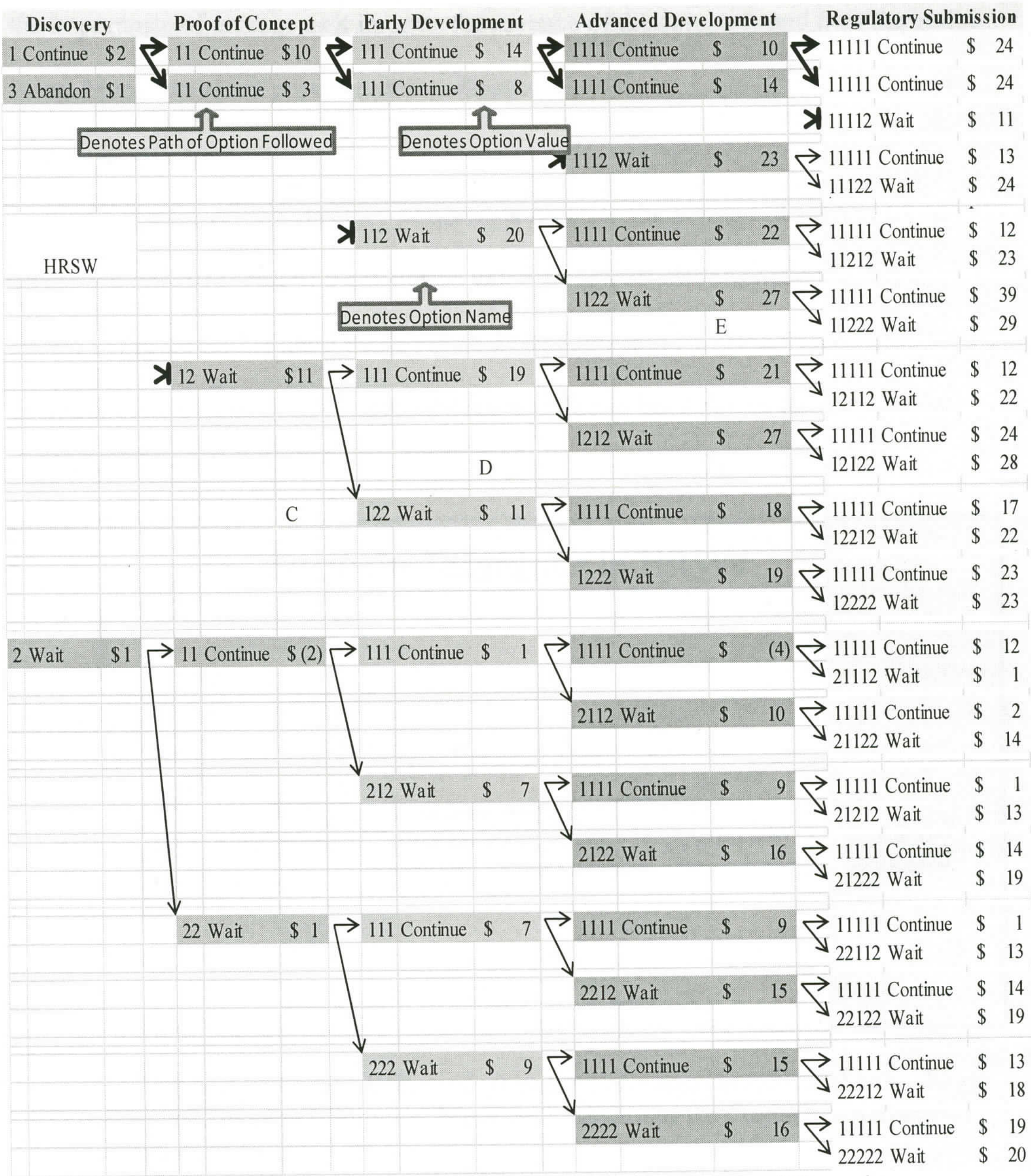


Figure 5.16. Trees Showing Possible Pathways and Option Values of Drought Tolerance in HRSW on Relative Scale. (1=Continue, 2=Wait, 3=Abandon) for Acreage in United States ($ in millions, c=.5).

The mean option values for drought tolerance in HRSW shows that it is out-of-money (Figure 5.15 and Figure 9 of Appendix B) for all the initial stages of development but it becomes ITM at last stage of development. However, when planted acreage of Canada is added this downside risk is further reduced. This also emphasizes the importance of acreage as it impacts the revenue of the company and thus the option value. More details are provided in sensitivity.

HRSW: Sensitivity

If acreage of Canada (19.7 M acres) is added to the acreage of USA (12.6 M acres), the downside risk of mean option value going out-of-money is mitigated as shown in Figure 5.17 (Figure 9 and Figure 24 of Appendix F). Drought tolerance becomes ITM after early developmental stage unlike in last stage as was the case in base case.

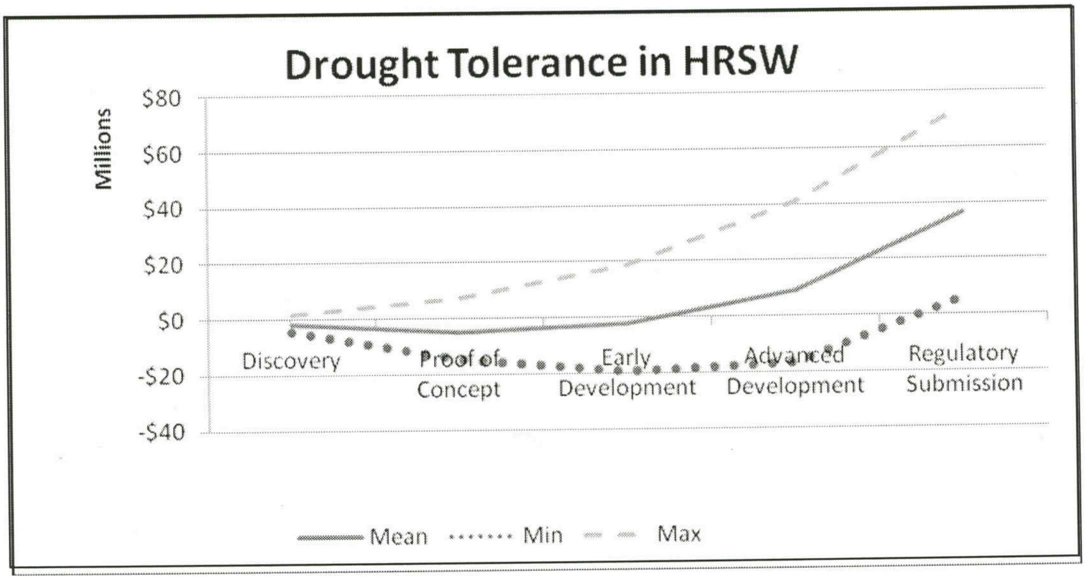


Figure 5.17. Change in Option Values of 'Drought Tolerance' in HRSW Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada ($ in millions, c=.7).

The time taken in developmental stages is most important for drought tolerance HRSW than Corn. Time taken in last stage, 2nd and 3rd stage is the most critical random variables for HRSW option value in regulatory stage (Figure 5.26, Figure 21 of Appendix B).

Figure 5.19 (and Figure 60 of Appendix F) shows the impact of increased share of potential technology fee a company can charge (at c =0.7). For combined acreages of

US and Canada, the effect of various shares of technology fee that company can charge, increase the option value at any given probability. The probability of increased option value causes shift to the right in cumulative distribution function. The variability has slightly increased for regulatory stage (the curve is flatter) there is 90 % chance that option value will be between 150 million and 260 million. With every stage, there is more increase in cash return relative to reduction in risk.

The results for other traits Cold Tolerance, NUE and All (stacked traits) are presented in appendixes.

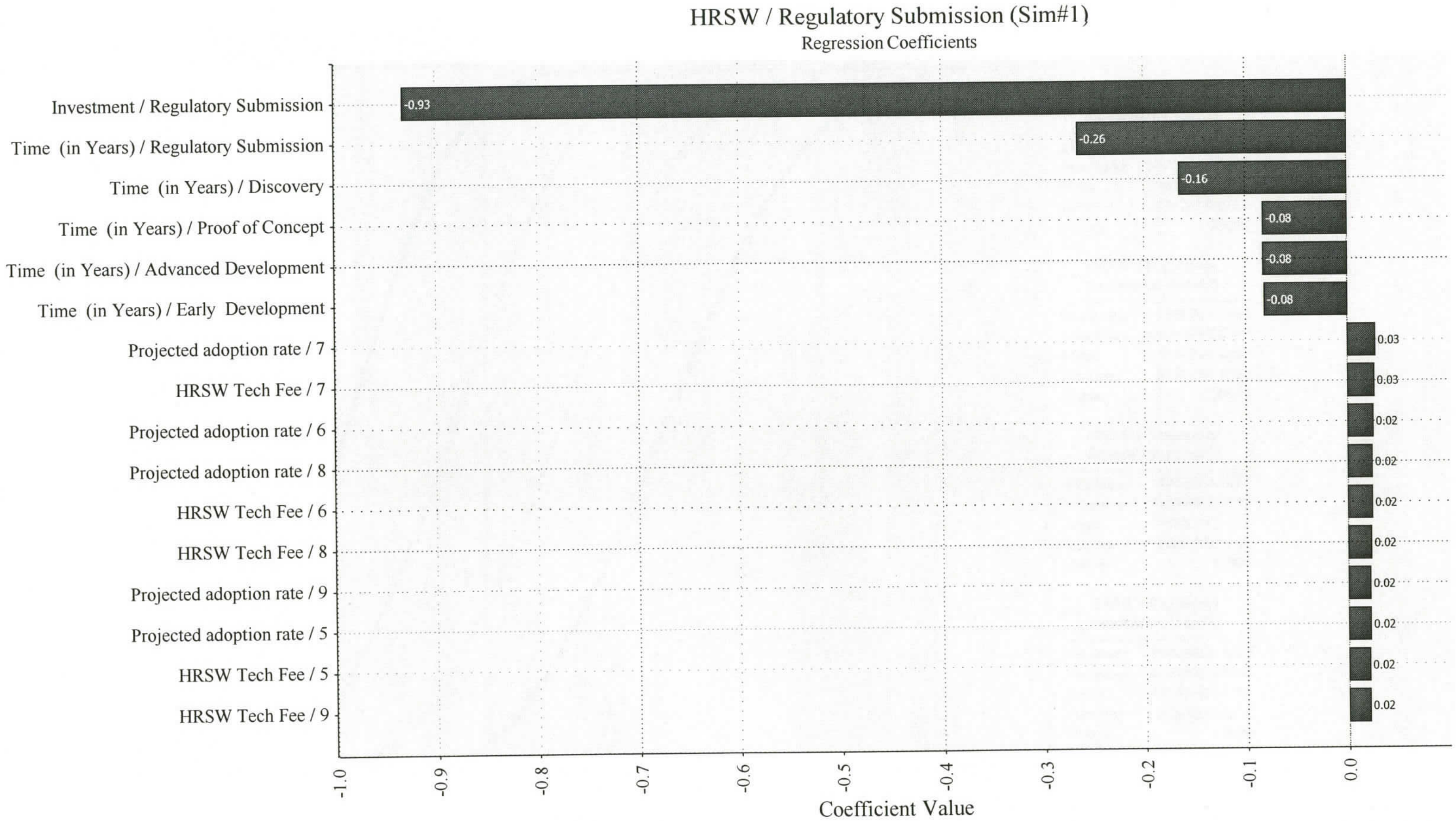


Figure 5.18. Tornado Graph Showing Regression Coefficients for Drought Tolerance During Regulatory Submission in HRSW for Acreage in United States ($ in billions, c=.5).

Sensitivity: Tech. Fees for Drought Tolerance in HRSW (Combined Acreage of United States and Canada at c=0.4, 0.5, 0.6, 0.7)

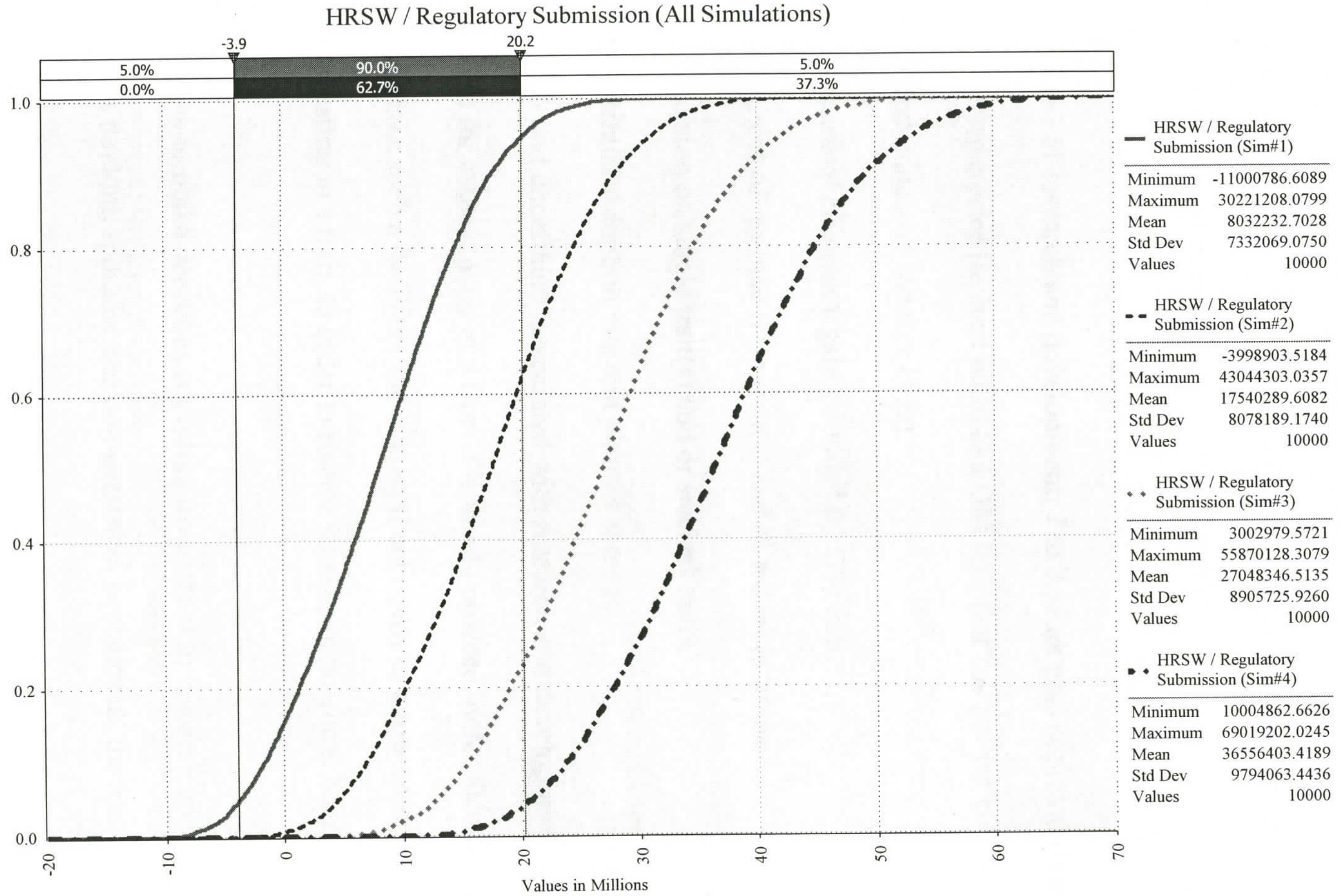


Figure 5.19. Cumulative Distribution for Option Values Across GM Traits at Regulatory Submission in HRSW (Sim #1=0.4, Sim #2=0.5, Sim #3=0.6, Sim #4=0.7) for Combined Acreage in United States and Canada ($ in millions).

SUMMARY AND CONCLUSIONS

Problem

Due to risk and uncertainty associated with research and development of GM trait, it is imperative for management of a firm if it should proceed, defer, license or abandon the trait. To make such a decision, the management needs to know with greatest predictability about investing in a trait, in order to realize maximum potential benefits from the R&D of trait. Some of the contributing factors to the problems are:

- Investment in developing one trait is about $100 million;
- Time of research and development: 7 to 8 years plus approval time of 3-4 years;
- Putting a price (to start with) to a GM trait that has not yet been commercialized.
- Randomness of inducer event.
- Technical efficiency gain provided by GM trait.
- Sources of revenue from trait(s) and its extent in future.
- Decision on single trait(s) and or stacked traits.
- Potential Adoption rate and planted acreage.

Due to risk and uncertainty associated with research and development of GM trait, it is imperative for management of a firm if it should proceed, defer, license or abandon the trait. To make such a decision, the management needs to know with greatest predictability about investing in a trait, in order to realize maximum potential benefits from the R&D of trait.

How to make decisions regarding investment in research and development of GM trait that is random, sporadic and non-persistent becomes all the more important.This thesis used real options approach model that can be used for valuing and pricing of GM traits that are random, sporadic and non-persistent.

Objectives

The purpose of this thesis was to develop model that can be used for valuing and pricing of GM traits that are random, sporadic, and non-persistent (e.g. drought tolerance, heat/cold stress) using the real option's approach. The efficiency gain in case of occurrence of random event happening and GM traits expressed is measured and used as a decision factor in determining the value of GM traits(s) at different phases of development.

The primary objective of this thesis was to best capture the risk and uncertainties associated with research and developmental phases of GM traits and their valuing and pricing using real options approach. Since real option approach indicates if the investment is in-the-money or out-of-money, it can help management decide prior to actual decision by comparing 'option values' calculated by model of this thesis. Addressing investment decisions, the thesis aimed at using documented sources and current industry trends for impact of adoption rate of GM trait(s), the distribution of technology fee, and planted acres on option value of GM trait.

Option values of GM trait based on future expected revenue from single trait and stacked traits show various possible pathways a management may chose. In order to use technology fee that best represents the possible source of revenue, we calculated risk premiums across varying risk attitudes of growers based on historical farm budgets. These risk premiums captured the value of reduced risk as perceived by the grower for any GM trait(s). These risk premiums were then treated as input for real option model allowing us to use a distribution of technology fees rather than a single value.

This study provided insights into how real options methodology can be applied to investment decisions for research and development of GM traits while best capturing risks and uncertainties associated before and after the trait is commercialized. Theoretical model of binomial options is developed in Chapter 3, Methodology on farm budgets and trait efficiency and results are presented in Chapter 4. Trait option model and results are presented in Chapter 5.

Procedures

A Binomial option model was used to model option value of the research project for any GM trait considered in this thesis. Future expected revenue of 15 years post commercialization was used to calculate the NPV and the binomial option tree was then derived using backward induction process. Nodal value of option trees represented the option value of research project for respective GM trait.

Farm Budgets

Farm budget data for Corn and HRSW from state report of North Dakota Farm Business Management Education Program was considered from year 1989 to 2007 to calculate risk premiums for various GM traits across risk attitude of growers for each crop. The range of ARAC utilized was from 0.00 to 0.15 for all the three crops (corn and HRSW) where the upper bound was estimated using methods developed by McCarl and Bessler (1989). A set values of risk premiums for risk neutral, slightly risk averse, and moderately risk averse grower is then used as input to get a distribution of technology fees in real option model

Real Option Model

Binomial Option model approach was used to model the option values of GM trait(s). Two possible options to "continue" and "wait" were modeled at each node. A new option tree is modeled at every point where there is possibility to wait. Thus option to 'wait' is modeled in pair with option to continue in a separate tree denoting another possible pathway. Such representation of model lays out the various possible option values of GM trait at different stages of development depending on the kind of choices made at different point of times. Binomial option model approach is based on Amram and Kulatlika, Jagle, 1999, and Flagg, Ian, and Wilson, 2007

Results: Overview

Corn

The risk premiums for drought tolerance in corn for risk neutral, slightly, and moderately risk averse grower were found to be \$0.46, \$16.54, and \$176.66, respectively. Similar values for cold tolerance are \$4.17, \$15.59, and \$126.11 whereas for NUE they were \$2.94, \$17.17, and \$162. For stacked trait (combination of all) it was \$4.88, \$20.15, and \$179.57. These values were used as distributions for expected technology fees in real option model.

Option values corn are in-the-money for all stages of development in base case. Option value of GM trait at regulatory submission for drought tolerance is \$5.96 billion when decision to continue was made during all previous stages. In case the management had decided to wait for regulatory submission, the option value of drought tolerance during same time is \$5.33 billion. Option value of cold tolerance during regulatory submission is

$4.49 billion while $5.6 billion for NUE. For stacked trait (combination of all) it was $6.3 billion which is highest.

The management should thus exercise the options for stacked (combination of drought, cold, and NUE) traits over any single individual trait. Among individual traits, drought tolerance has highest value.

HRSW

The risk premiums for drought tolerance in HRSW for risk neutral, slightly, and moderately risk averse growers were found to be $2.32, $2.66, and $3.04, respectively. Similar values for Cold tolerance are $(0.49), $(0.20), and $(0.15) whereas for NUE they were $1.66, $1.71, and $1.60. For stacked trait (combination of all) they were $5.71, $6.04, and $6.40. These values were used as distributions for expected technology fees in real option model.

Option values HRSW were both in-the-money (initial stages) and out-of-money (during last stages). Option value of GM trait at regulatory submission for drought tolerance is $24 million when 50% of potential technology fee is charged by company for planted acreage of United States (when decision to continue was made during all previous stages). In case the management had decided to wait for regulatory submission, the option value of drought tolerance during same time is $11 million. Option values show increase in ITM values with increase in share of technology fees or with increase in share of technology fees charged by the company.

Management should thus exercise the options for stacked (combination of drought, cold, and NUE) traits and if it were to choose the development of only one trait then it should chose the development of stacked trait over investment in development of single traits. Among individual traits, drought tolerance has highest value. The management will certainly not exercise option of developing NUE in HRSW as it out-of-money.

Managerial Implications

The analysis and results from thesis show that there is more value to the management in making choices as the events unfold. Some the option values for GM traits are in-money in case they decide to continue investing during all the stages of development. However, in most of the cases it was found that option values for GM trait for various traits were out-of-money initially, but they become in-the-money during regulatory submission. This suggests that in case the decisions are made only at initial stages, the management is not likely to invest in development of GM traits which would have been potentially beneficial.

Contributions, Limitations and Further Research

This thesis contributes to modeling of not various option values in an option tree at each node but also in presenting various such option trees, where in each option tre represents a possible pathway. The nodal values of option tree are presented on same relative time frame, thus helpful in comparing the option values of GM trait under various scenarios. Since binomial model allows two choices at each node, start of another tree helps in comparing the third option of deferring the investment.

The findings of this thesis are limited by factors of non-availability of historical data as to how many times the decision to continue investing, abandon or post pone was taken during development of certain GM trait. Thus, single period probabilities do not suggest the likelihood of company preferring one option over another. Secondly, there is no documented evidence regarding technical efficiency gain provided by any GM trait in specific numerical terms. Thirdly, the technology fees charged by companies for a GM trait is no where documented. Previous studies have assumed numeric values for their purpose of study. Also, the adoption rate and planted acres in future, which helps derive option value is highly uncertain. The distribution of risk attitude of growers towards various GM traits for different crops is also not known.

If the risk attitudes of growers, as calculated in this study, are close to actual figures, then there can be two major implications:

1. If the actual risk attitudes of growers are lower than those calculated, then there will be slower adoption of GM traits as they will perceive the share of technology fee to be higher.
2. In case the actual risk attitude is higher than those calculated in thesis, growers will be quick to adopt the GM traits, because growers perceive the value of GM traits to be much higher than what is calculated in this thesis.

More documented research is required to know the risk attitude of growers towards various GM traits in different crops. In this thesis we assumed their distribution. Similarly, the technical efficiency gain from GM traits needs to specifically mention. Currently, they are not. Also, if historical date regarding projects of research and development, the decisions made, their frequencies are known, then multiple option model can be used.

Since there is no published information as to what share of potential technology fee is charged by GM trait developing companies, the assumption of 50 % for the base case captures only part of possible scenarios. Variation in share of technology fee was used in sensitivity analysis.

This model assumes for the sake of simplicity that GM traits will released in United States. However as the sensitivity analysis shows, GM traits are out-of-money for small acreage. Practically, also, the companies are likely to develop GM traits for global application with similar growing conditions rather than focus on a smaller geographical area. Another point of concern that is left un-captured in this thesis is the amount of loss from unlicensed use of GM traits where in the company does not get any revenue. In the sensitivity analysis, the thesis assumes that combination of US and Canada acreage leads to increase in revenue. This may not be true when other geographic areas with different agronomic practices will be considered as their cost of growing and thus benefit achieved by GM trait will be different. Not to mention, with increase in geographic area considered, there will be more variation in risk attitude of growers and other social and political issues that may play major role in the extent of share of technology fees available to GM trait developing company.

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APPENDIX A

This Appendix contains tables showing parameters of distributions assumed in base case farm budgets calculation of risk premiums for various traits. Various GM traits represent the distribution used in simulation as suggested by the historical data and variable like yield, price, seed, chemical and fertilizer which have been treated as random.

Table A.1. Trait Development Assumptions for Corn, and HRSW.

Trait Development Assumptions For Corn, and HRSW.					
	Discovery	Proof of Concept	Early Development	Advanced Development	Regulatory Submission
Time (in Years)	=Uniform(2, 4)	=Uniform(1, 2)	=Uniform(1, 2)	=Uniform(1, 2)	=Uniform(1, 3)
Investment	=Uniform(2000000, 5000000)	=Uniform(5000000, 10000000)	=Uniform(10000000, 15000000)	=Uniform(15000000, 30000000)	=Uniform(20000000, 40000000)
Cumulative	0.05	0.25	0.5	0.75	0.9
Single Period	0.20	0.50	0.67	0.83	0.90

Table A.2. Random Variables and Parameters Base Case in Corn.

Corn	Random Variables and Parameters Base Case				
	Base Case	Drought Tolerance	Cold Tolerance	NUE	All
Yield	=Logistic(84.26,14.31)	*=Extvalue(71,23.70)*	*=Logistic(88.47,15.05)*	=Logistic(84.26,14.31)	*=Triang(13.9,122.55,122.55)*
Price	=Extvalue(2.01,0.32)	=Extvalue(2.01,0.32)	=Extvalue(2.01,0.32)	=Extvalue(2.01,0.32)	=Extvalue(2.01,0.32)
Seed Cost	=Extvalue(20.90,6.28)	=Extvalue(20.90,6.28)	=Extvalue(20.90,6.28)	=Extvalue(20.90,6.28)	=Extvalue(20.90,6.28)
Chemical Cost	=Uniform(12.69,27.33)	=Uniform(12.69,27.33)	=Uniform(12.69,27.33)	=Uniform(12.69,27.33)	=Uniform(12.69,27.33)
Fertilizer	=Normal(25.00,8.80)	=Normal(25.00,8.80)	=Normal(25.00,8.80)	*=Uniform(11.42,24.59)*	*=Uniform(11.42,24.59)*

Table A.3. Random Variables and Parameters Base Case in HRSW.

HRSW	Random Variables and Parameters Base Case				
	Base Case	Drought Tolerance	Cold Tolerance	NUE	All
Yield	=Logistic(32.01,3.10)	*=Logistic(33.4559,2.5129)*	*=Logistic(32.6897,2.7004)*	=Logistic(32.01,3.10)	*=Logistic(33.4559,2.5129)*
Price	=Extvalue(3.34,0.59)	=Extvalue(3.34,0.59)	=Extvalue(3.34,0.59)	=Extvalue(3.34,0.59)	=Extvalue(3.34,0.59)
Seed Cost	=Normal(8.09,1.57)	=Normal(8.09,1.57)	=Normal(8.09,1.57)	=Normal(8.09,1.57)	=Normal(8.09,1.57)
Chemical Cost	=Logistic(10.61,3.05)	=Logistic(10.61,3.05)	=Logistic(10.61,3.05)	=Logistic(10.61,3.05)	=Logistic(10.61,3.05)
Fertilizer	=Invgauss(32.46,777.4,RiskShift(-15.77))	=Invgauss(32.46,777.4,RiskShift(-15.77))	=Invgauss(32.46,777.4,RiskShift(-15.77))	*=Invgauss(25.968,621.93,RiskShift(-12.619)*	*=Invgauss(25.968,621.93,RiskShift(-12.619)*

APPENDIX B

This appendix shows the base case results for various traits considered, across stages in corn and HRSW. The dollar values are presented in US dollars at technology fee sharing © of 50% (0.5) for planted acreage of USA only. The values are shown for a maximum, mean, and minimum dollar value of options, based on expected revenue by a GM trait.

Base Case Results

Corn

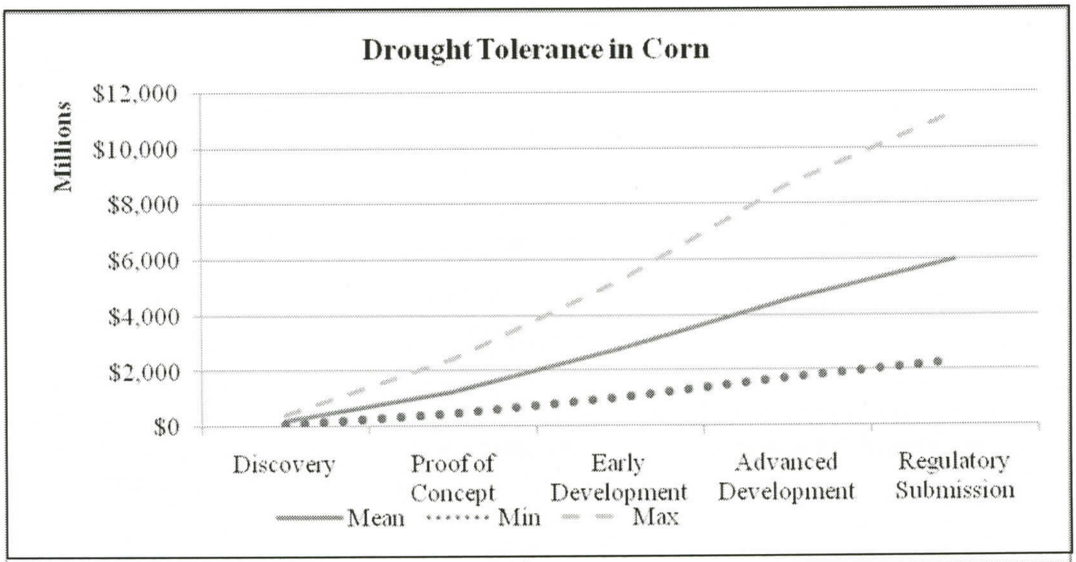


Figure B.1. Change in Option Values of 'Drought Tolerance' in Corn Across Stages of Development Showing Minimum, Mean, and Maximum for Acreage in United States ($ in millions, c=.5).

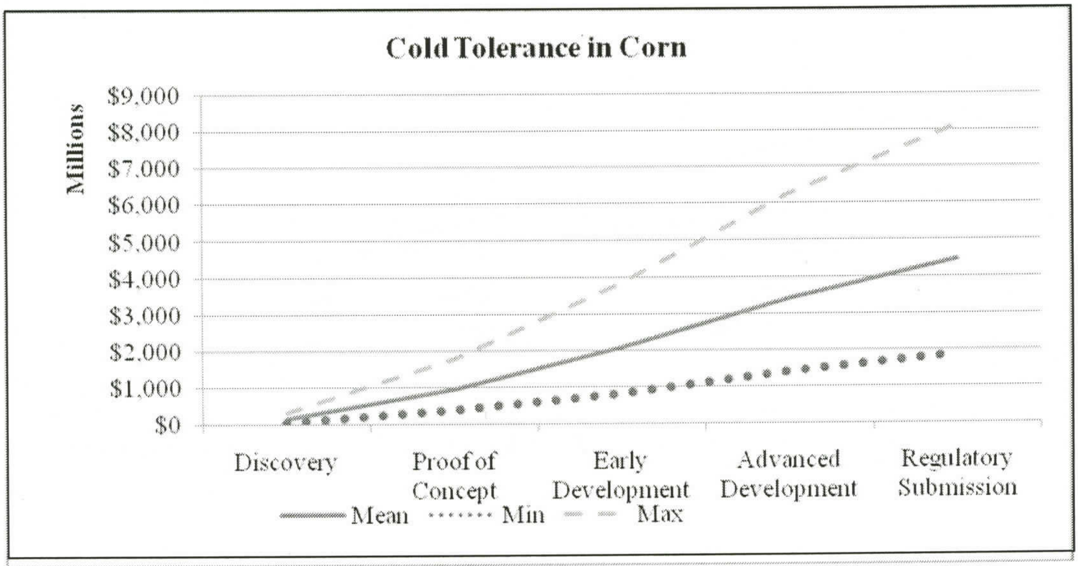


Figure B.2. Change in Option Values of 'Cold Tolerance' in Corn Across Stages of Development Showing Minimum, Mean, and Maximum for Acreage in United States ($ in millions, c=.5).

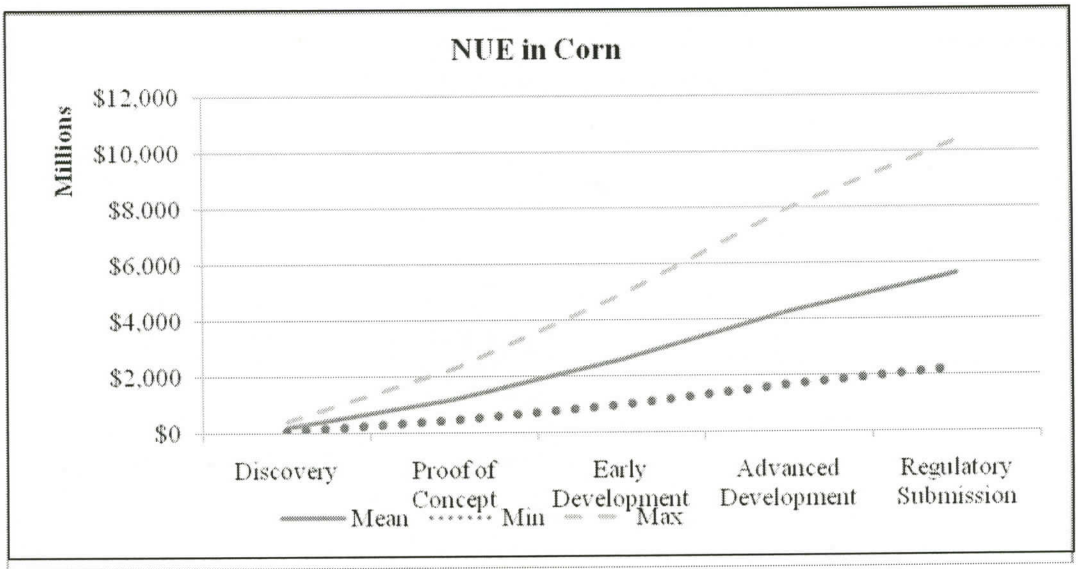


Figure B.3. Change in Option Values of 'Nitrogen Use Efficiency' in Corn Across Stages of Development Showing Minimum, Mean, and Maximum for Acreage in United States ($ in millions, c=.5).

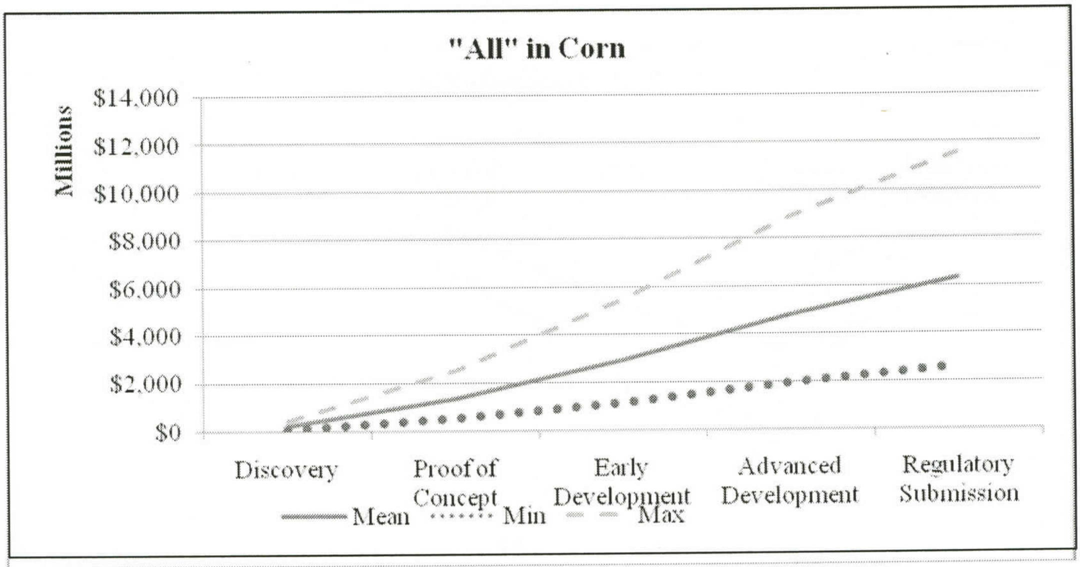


Figure B.4. Change in Option Values of 'All' in Corn Across Stages of Development Showing Minimum, Mean, and Maximum for Acreage in United States ($ in millions, c=.5).

HRSW

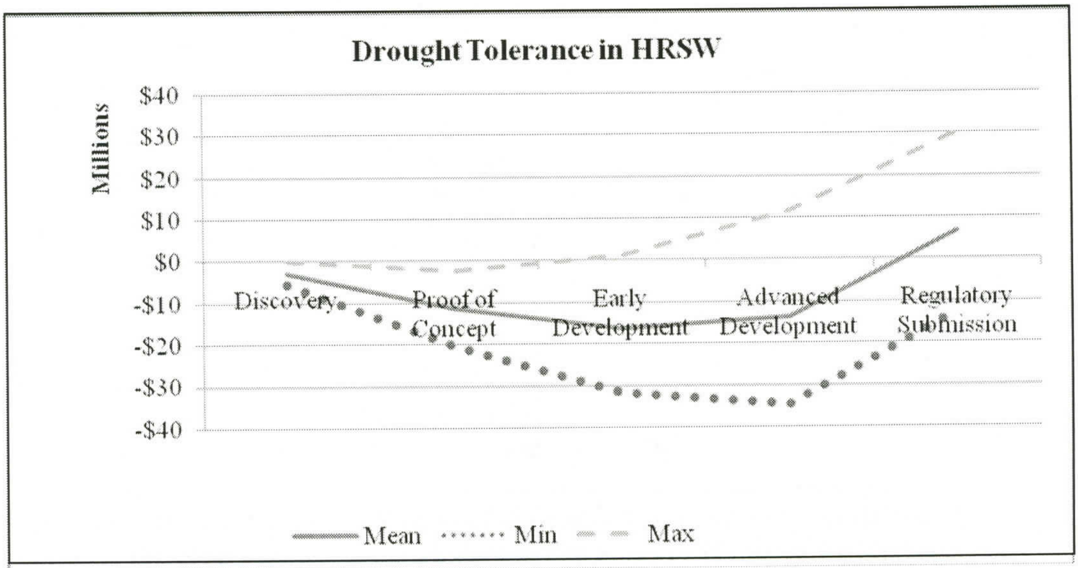


Figure B.5. Change in Option Values of 'Drought Tolerance' in HRSW Across Stages of Development Showing Minimum, Mean, and Maximum for Acreage in United States ($ in millions, c=.5).

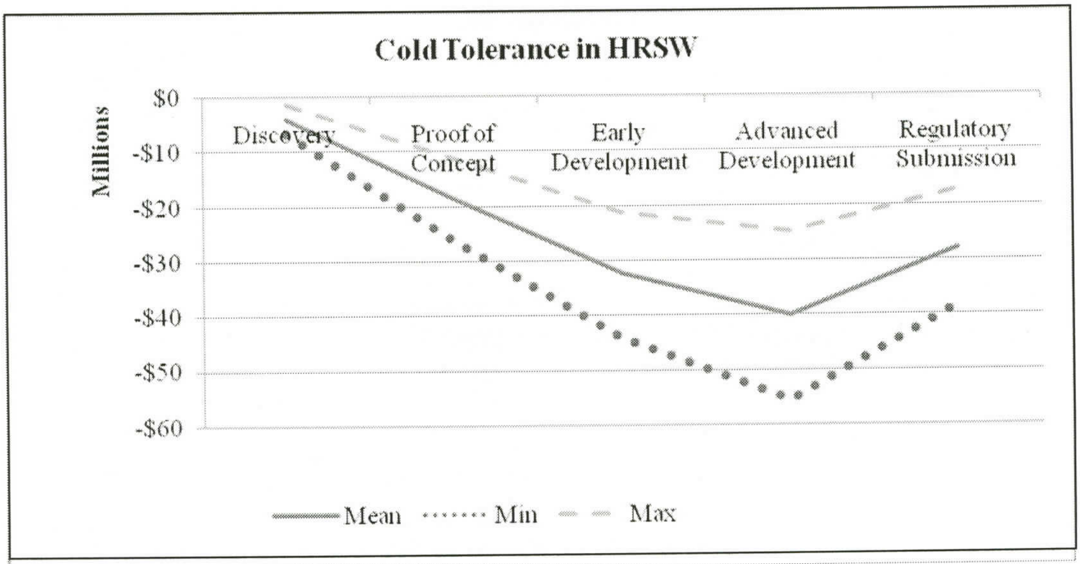


Figure B.6. Change in Option Values of 'Cold Tolerance' in HRSW Across Stages of Development Showing Minimum, Mean, and Maximum for Acreage in United States ($ in millions, c=.5).

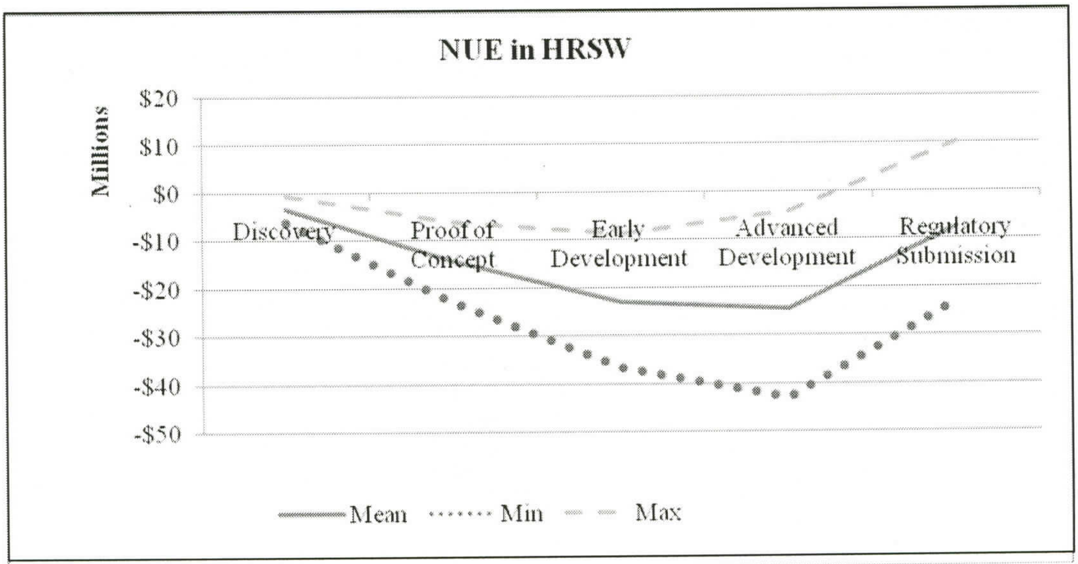


Figure B.7. Change in Option Values of 'Nitrogen Use Efficiency' in HRSW Across Stages of Development Showing Minimum, Mean, and Maximum for Acreage in United States ($ in millions, c=.5).

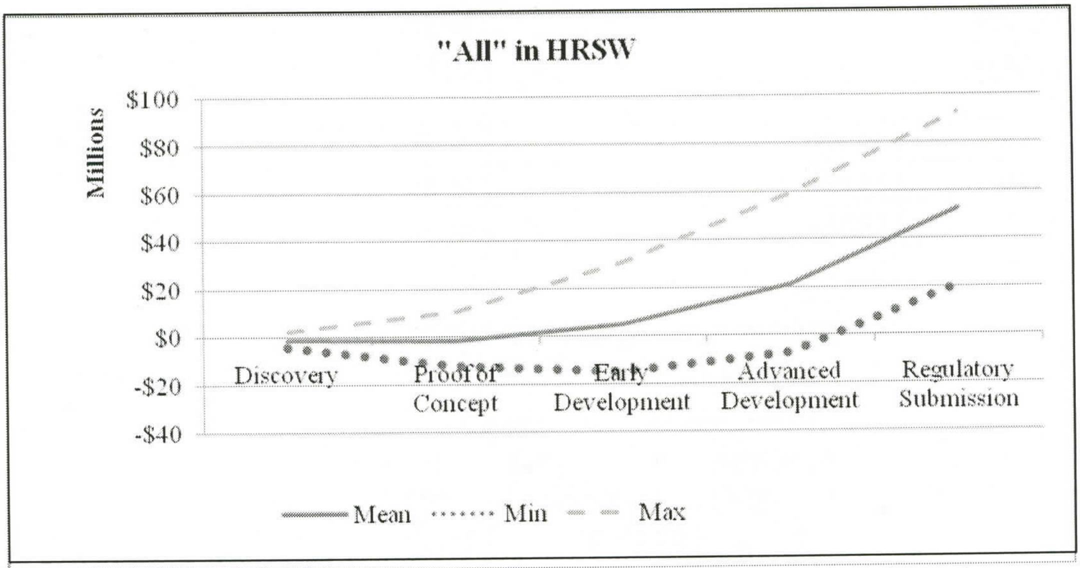


Figure B.8. Change in Option Values of 'All' in HRSW Across Stages of Development Showing Minimum, Mean, and Maximum for Acreage in United States ($ in millions, c=.5).

Table B.1. Option Tree Showing Minimum, Mean, and Maximum Option Values for Drought Tolerance in Crops for Acreage in United States. ($ in millions, c=.5).

Drought Tolerance ($ in millions)					
Corn	Discovery	Proof of Concept	Early Development	Advanced Development	Regulatory Submission
Min	75.21	465.74	1024.00	1725.44	2298.74
Mean	211.99	1264.94	2767.88	4541.03	5967.82
Max	425.22	2422.72	5260.70	8661.54	11241.47
HRSW					
Min	-5.67	-20.44	-31.72	-34.61	-12.61
Mean	-2.84	-11.33	-16.27	-13.74	6.59
Max	-0.01	-2.46	0.97	11.43	30.28

Table B.2. Option Tree Showing Minimum, Mean, and Maximum Option Values for Cold Tolerance in Crops for Acreage in United States. ($ in millions, c=.5).

Cold Tolerance					
Corn	Discovery	Proof of Concept	Early Development	Advanced Development	Regulatory Submission
Min	60.72	377.84	831.67	1403.28	1873.68
Mean	158.66	948.08	2076.67	3410.23	4487.86
Max	311.52	1779.89	3846.52	6268.72	8142.36
HRSW					
Min	-6.77	-26.35	-44.33	-55.55	-38.41
Mean	-4.08	-18.73	-32.40	-40.13	-27.95
Max	-1.32	-11.25	-21.25	-24.87	-17.34

Table B.3. Option Tree Showing Minimum, Mean, and Maximum Option Values for NUE in Crops for Acreage in United States. ($ in millions, c=.5).

Nitrogen Use Efficiency (NUE)					
Corn	Discovery	Proof of Concept	Early Development	Advanced Development	Regulatory Submission
Min	73.53	455.55	1001.70	1688.08	2249.45
Mean	199.11	1188.43	2600.99	4268.00	5610.49
Max	395.08	2253.55	4872.79	7997.25	10381.10
HRSW					
Min	-6.11	-22.82	-36.81	-43.05	-22.90
Mean	-3.34	-14.33	-22.80	-24.43	-7.41
Max	-0.61	-6.17	-8.65	-4.17	10.28

Table B.4. Option Tree Showing Minimum, Mean, and Maximum Option Values for 'All' in Crops for Acreage in United States. ($ in millions, c=.5).

ALL					
Corn	Discovery	Proof of Concept	Early Development	Advanced Development	Regulatory Submission
Min	84.91	524.61	1152.81	1941.20	2583.41
Mean	224.21	1337.50	2926.18	4800.00	6306.78
Max	441.72	2520.07	5445.59	8902.48	11553.53
HRSW					
Min	-4.25	-12.52	-14.83	-7.46	20.62
Mean	-1.18	-1.47	5.25	21.46	52.67
Max	2.28	10.61	30.48	59.28	92.51

APPENDIX C

This appendix contains tables showing Ascending Cumulative Distributions for option values across GM traits at a particular stage. It also shows similar figures for a GM trait across stages of development. Tornado graphs showing regression coefficients for GM trait are presented for crops.

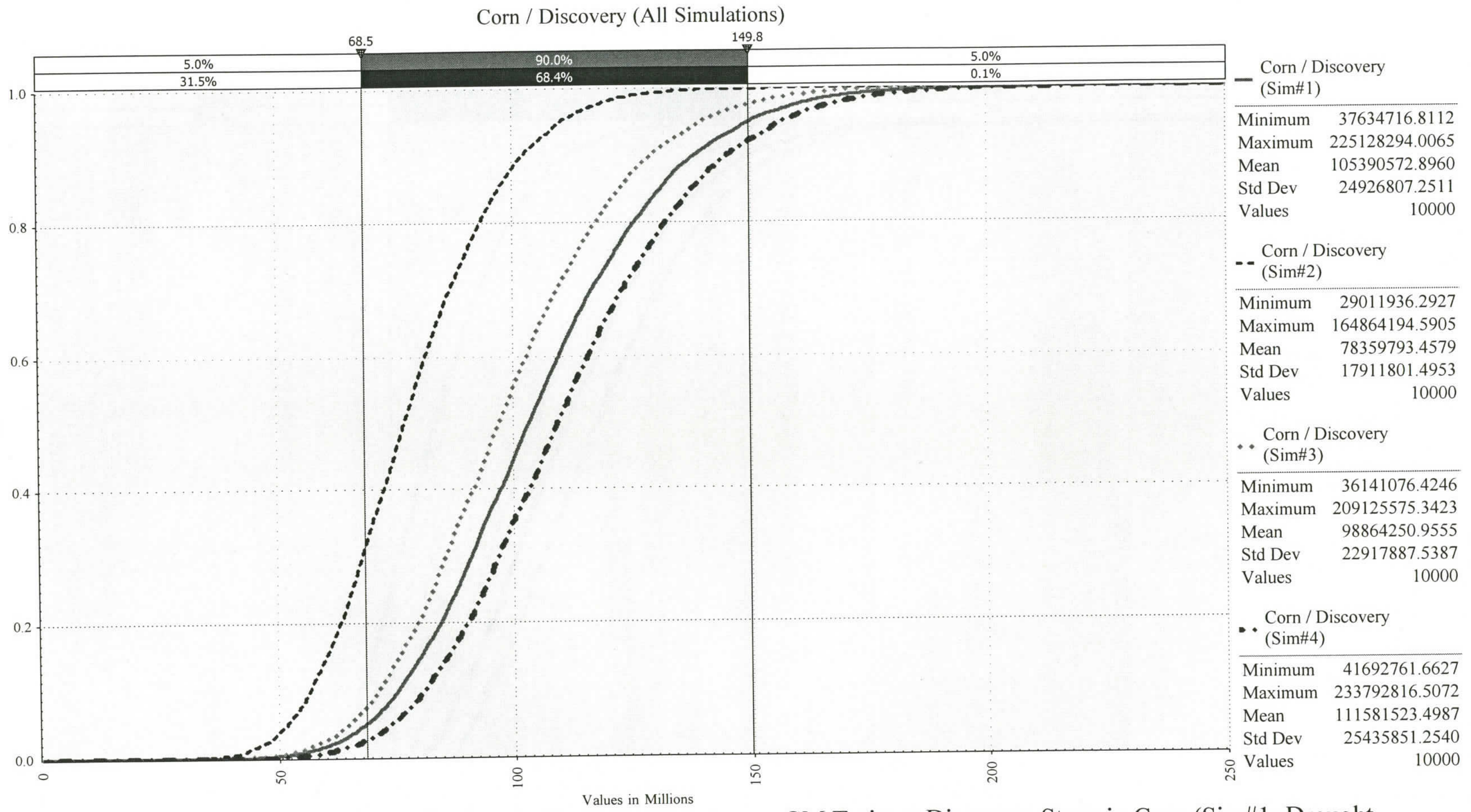


Figure C.1. Ascending Cumulative Distribution for Option Values Across GM Traits at Discovery Stage in Corn (Sim#1=Drought, Sim#2=Cold, Sim#3=NUE,Sim#4='All") for Acreage in United States ($ in millions, c=.5).

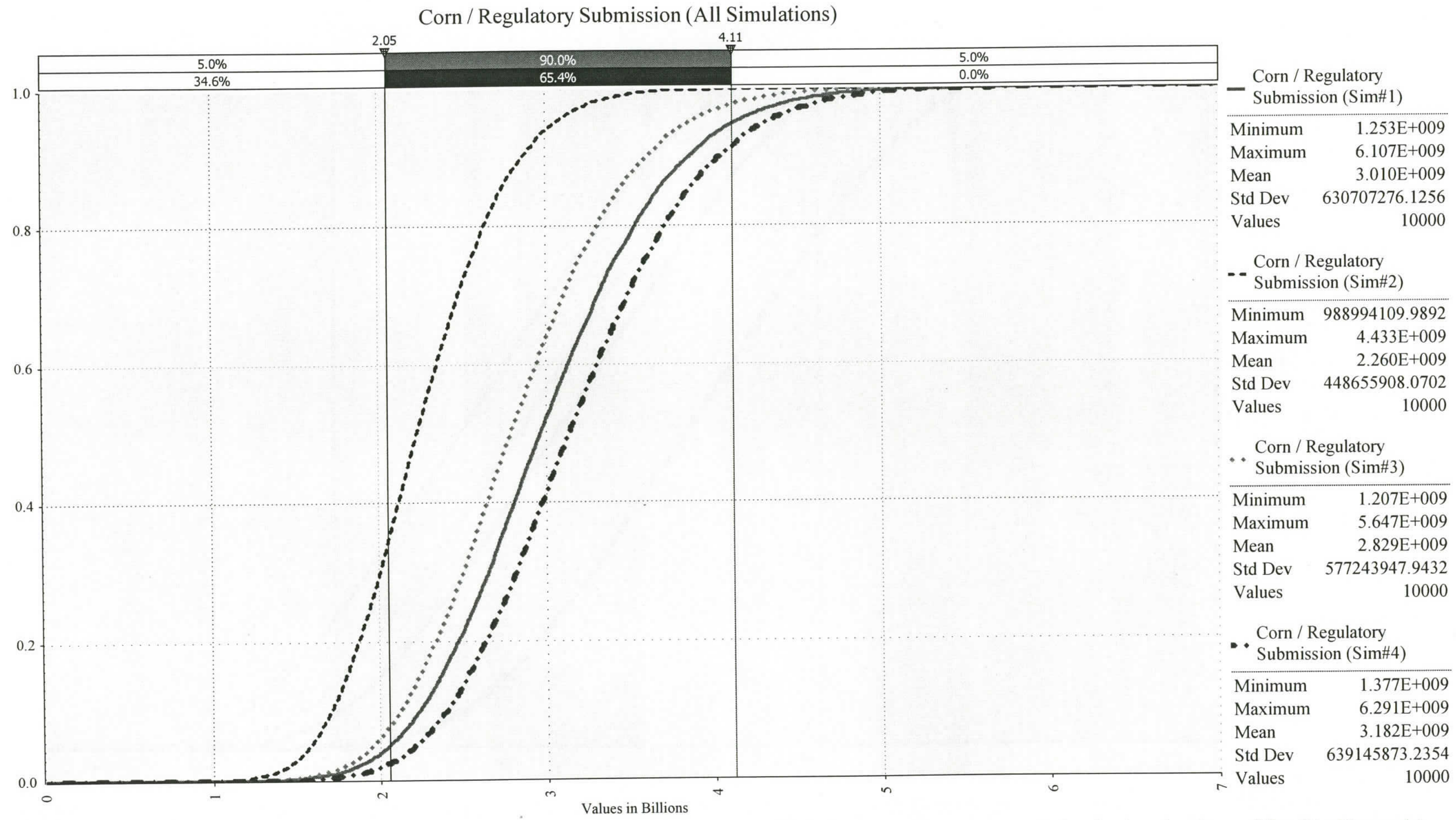


Figure C.2. Ascending Cumulative Distribution for Option Values Across GM Traits at Regulatory Submission in Corn (Sim#1=Drought, Sim#2=Cold, Sim#3=NUE,Sim#4='All") for Acreage in United States ($ in millions, c=.5).

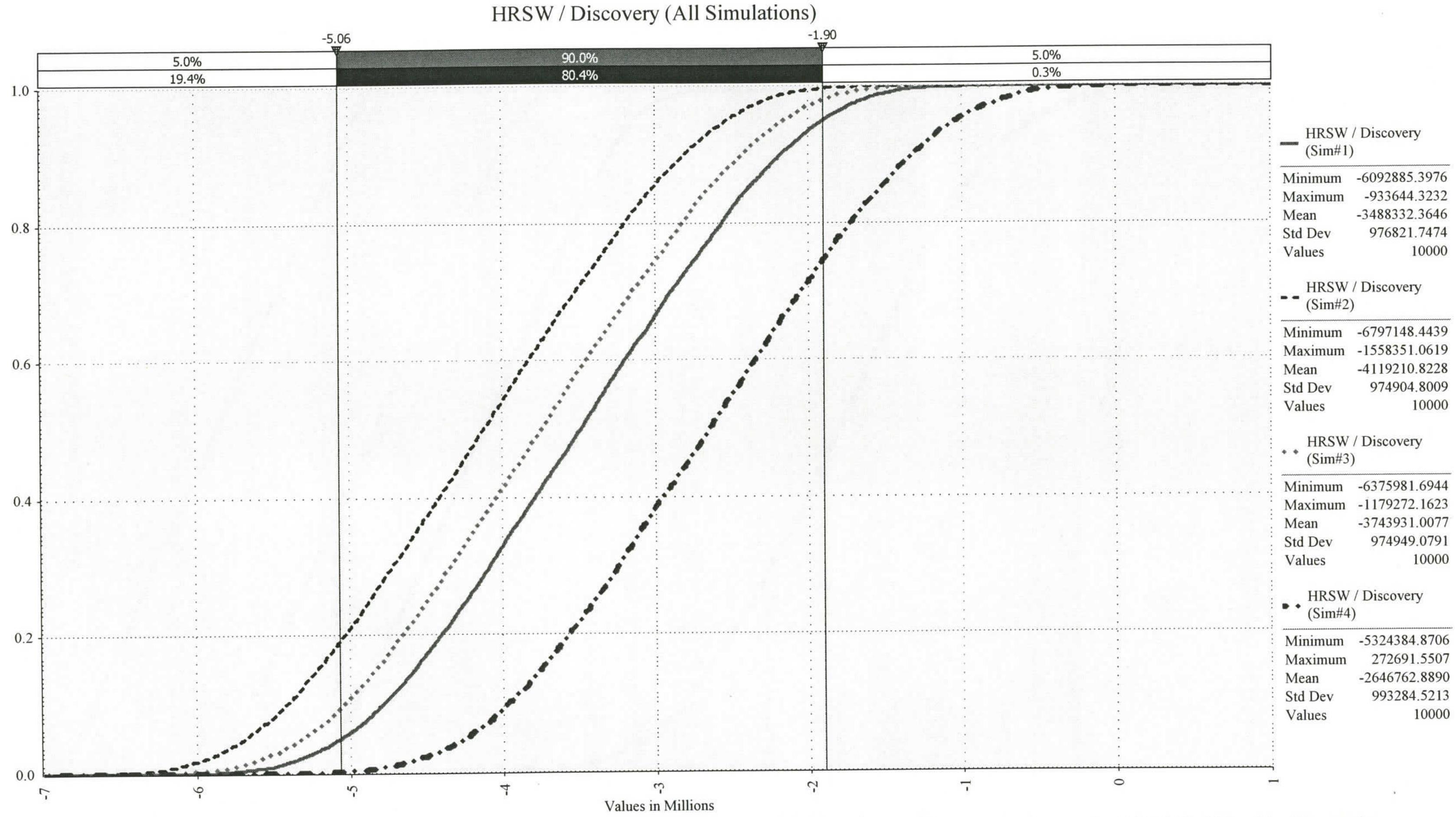


Figure C.3. Ascending Cumulative Distribution for Option Values Across GM Traits at Discovery Stage in HRSW (Sim#1=Drought, Sim#2=Cold, Sim#3=NUE,Sim#4='All") for Acreage in United States ($ in millions, c=.5).

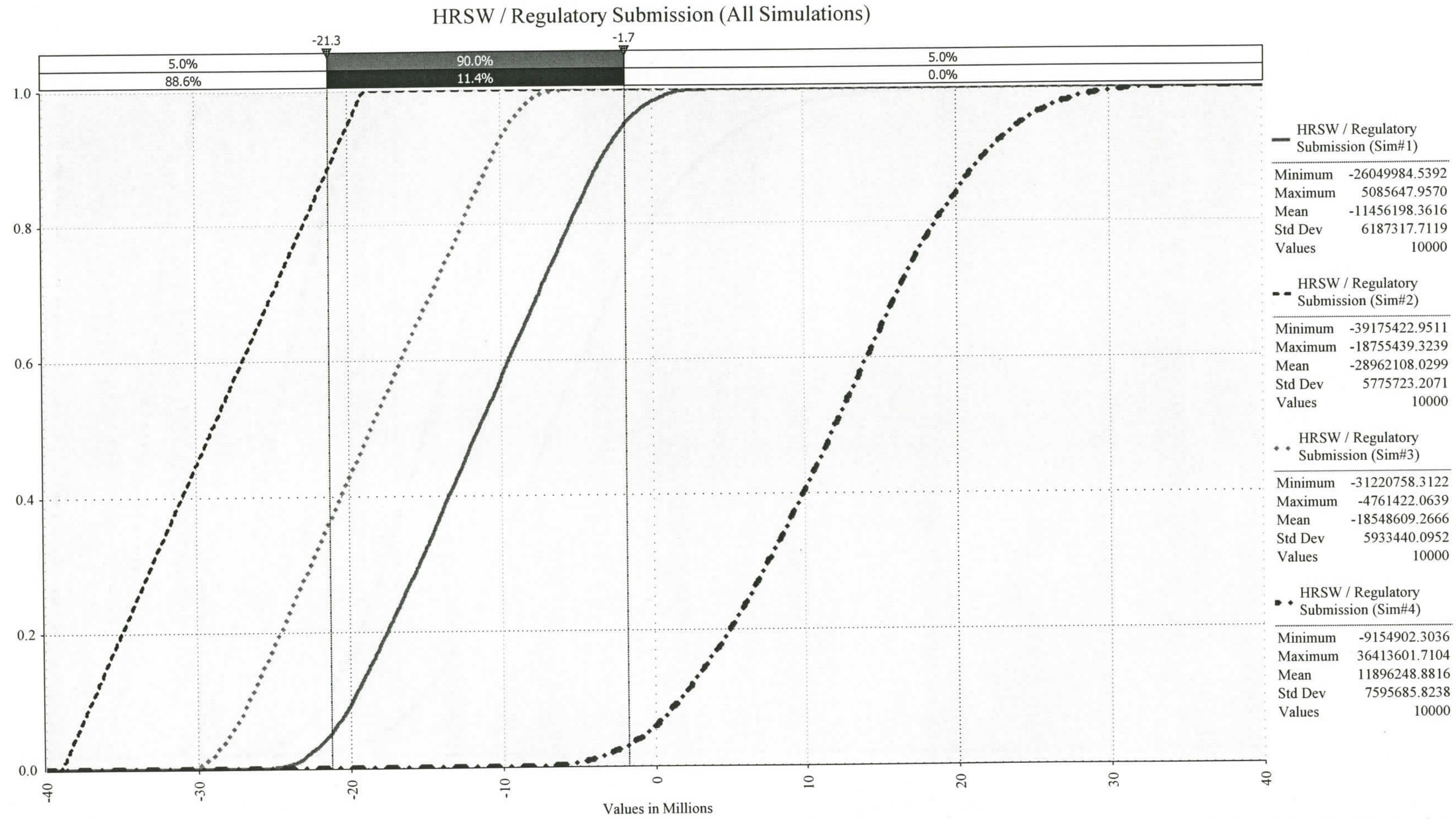


Figure C.4. Ascending Cumulative Distribution for Option Values Across GM Traits at Regulatory Submission in HRSW (Sim#1=Drought, Sim#2=Cold, Sim#3=NUE,Sim#4='All") for Acreage in United States ($ in millions, c=.5).

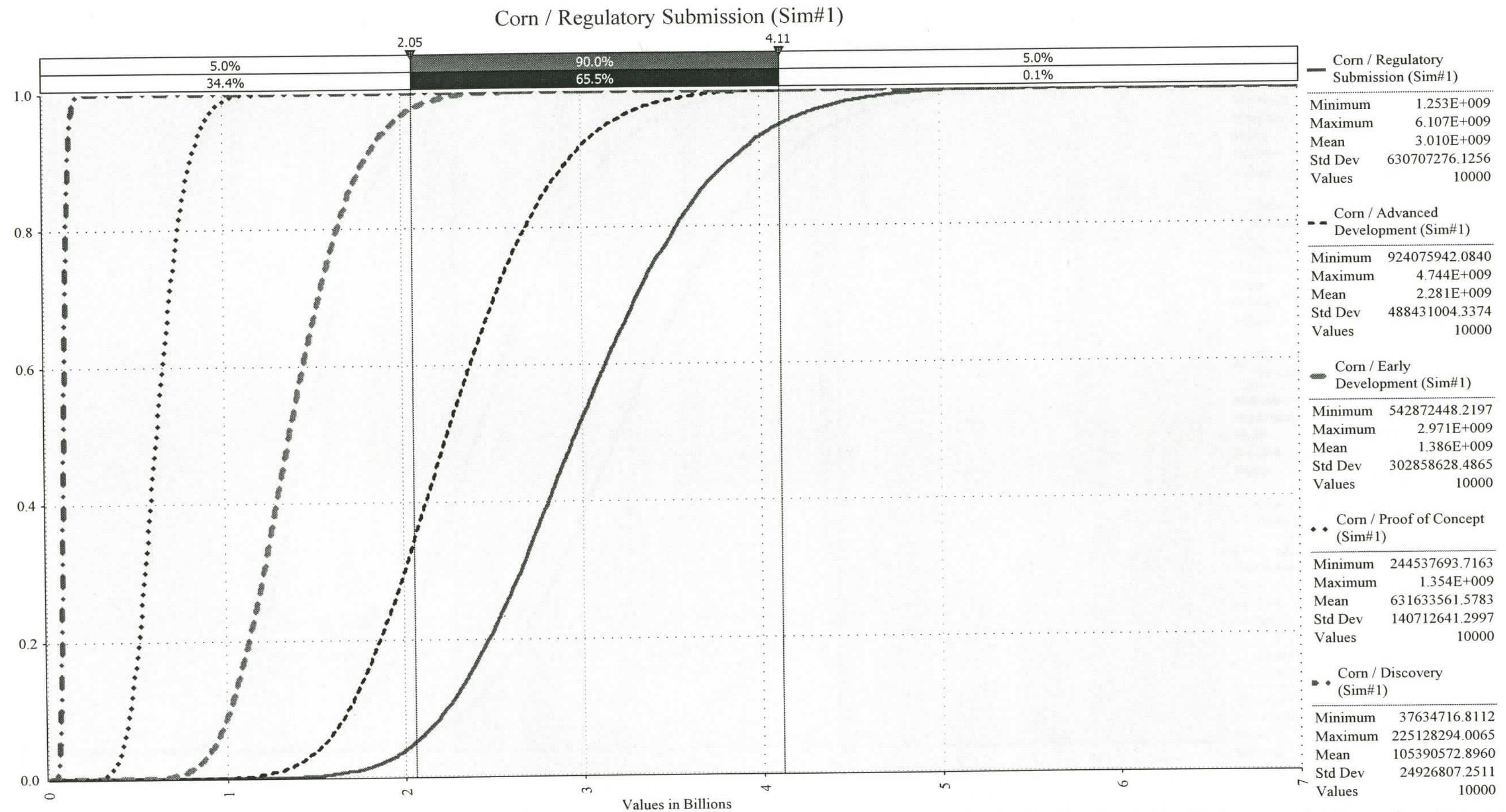


Figure C.5. Ascending Cumulative Distribution for Option Values Across Stages of Development for Drought Tolerance in Corn for Acreage in United States ($ in billions, c=.5).

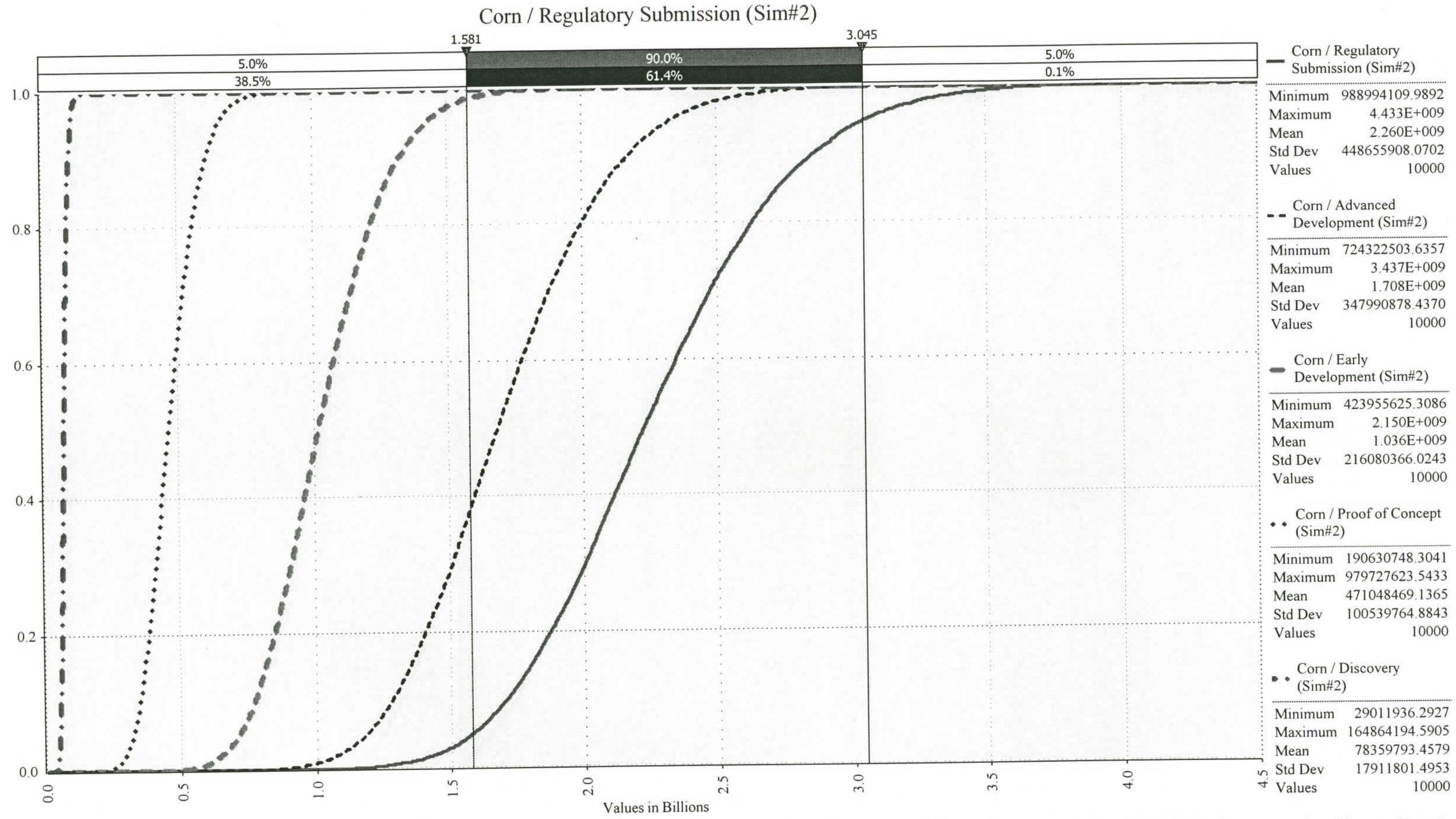


Figure C.6. Ascending Cumulative Distribution for Option Values Across Stages of Development for Cold Tolerance in Corn for Acreage in United States ($ in billions, c=.5).

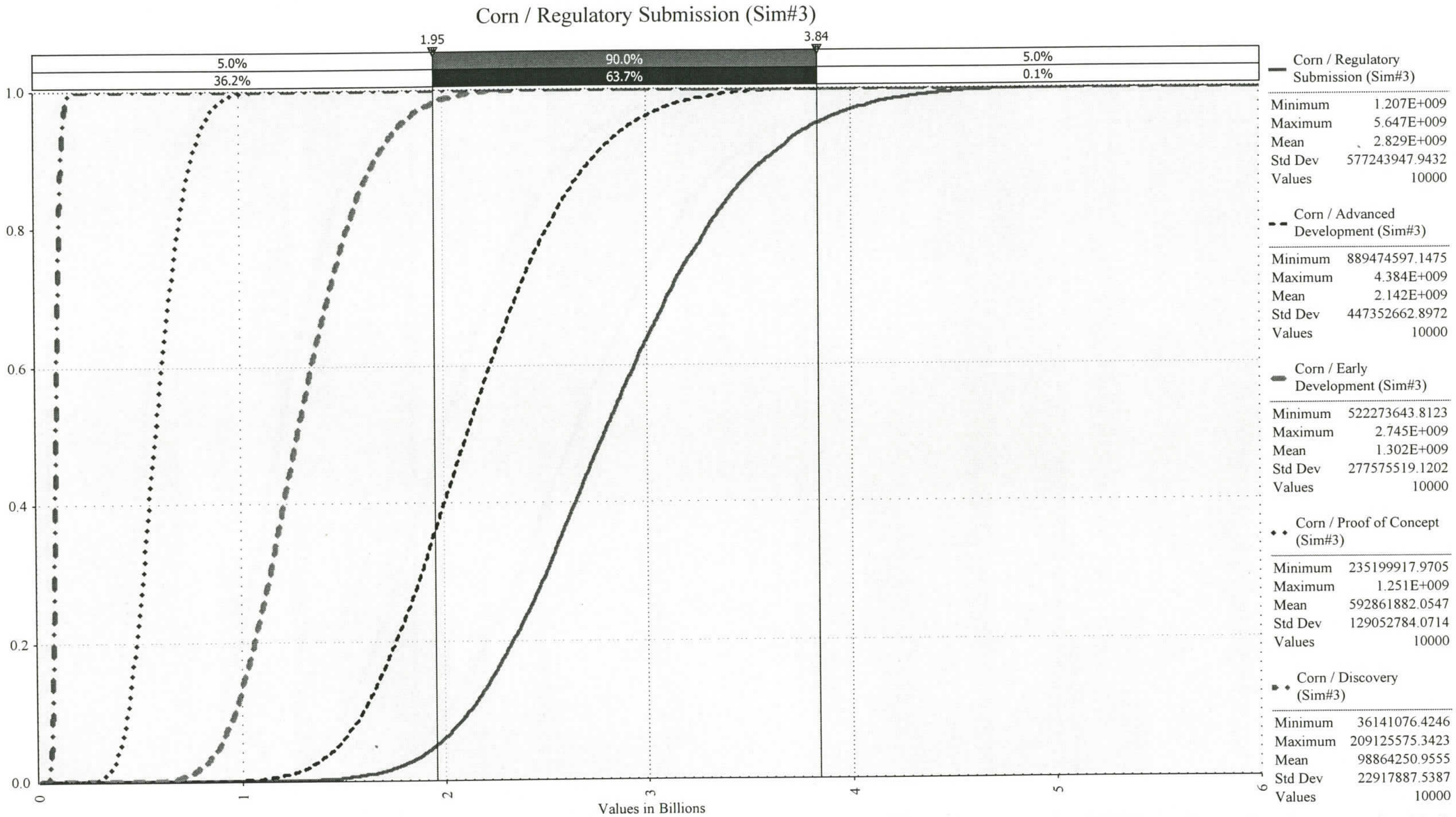


Figure C.7. Ascending Cumulative Distribution for Option Values Across Stages of Development for NUE in Corn for Acreage in United States ($ in billions, c=.5).

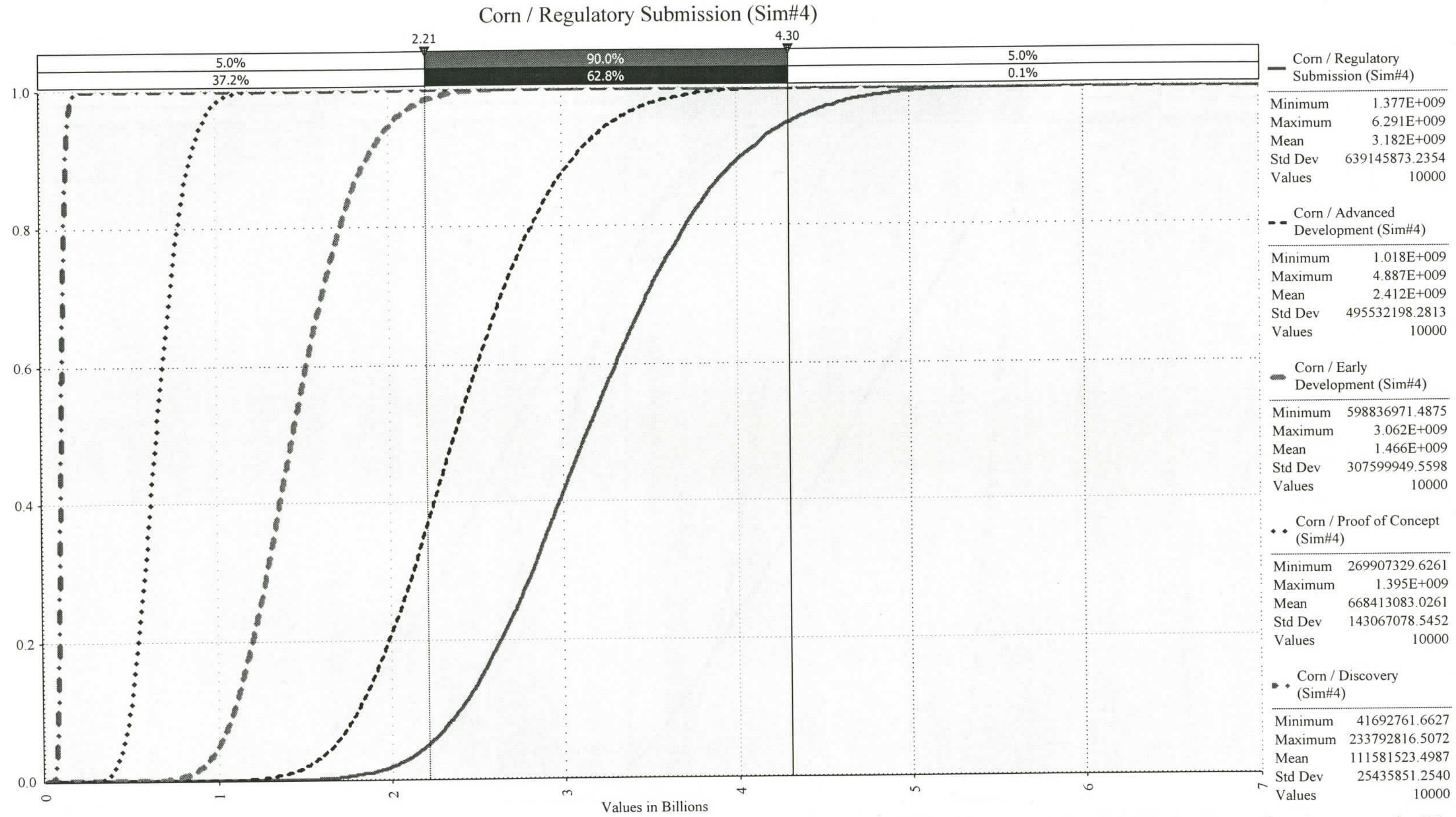


Figure C.8. Ascending Cumulative Distribution for Option Values Across Stages of Development for “All” in Corn for Acreage in United States ($ in billions, c=.5).

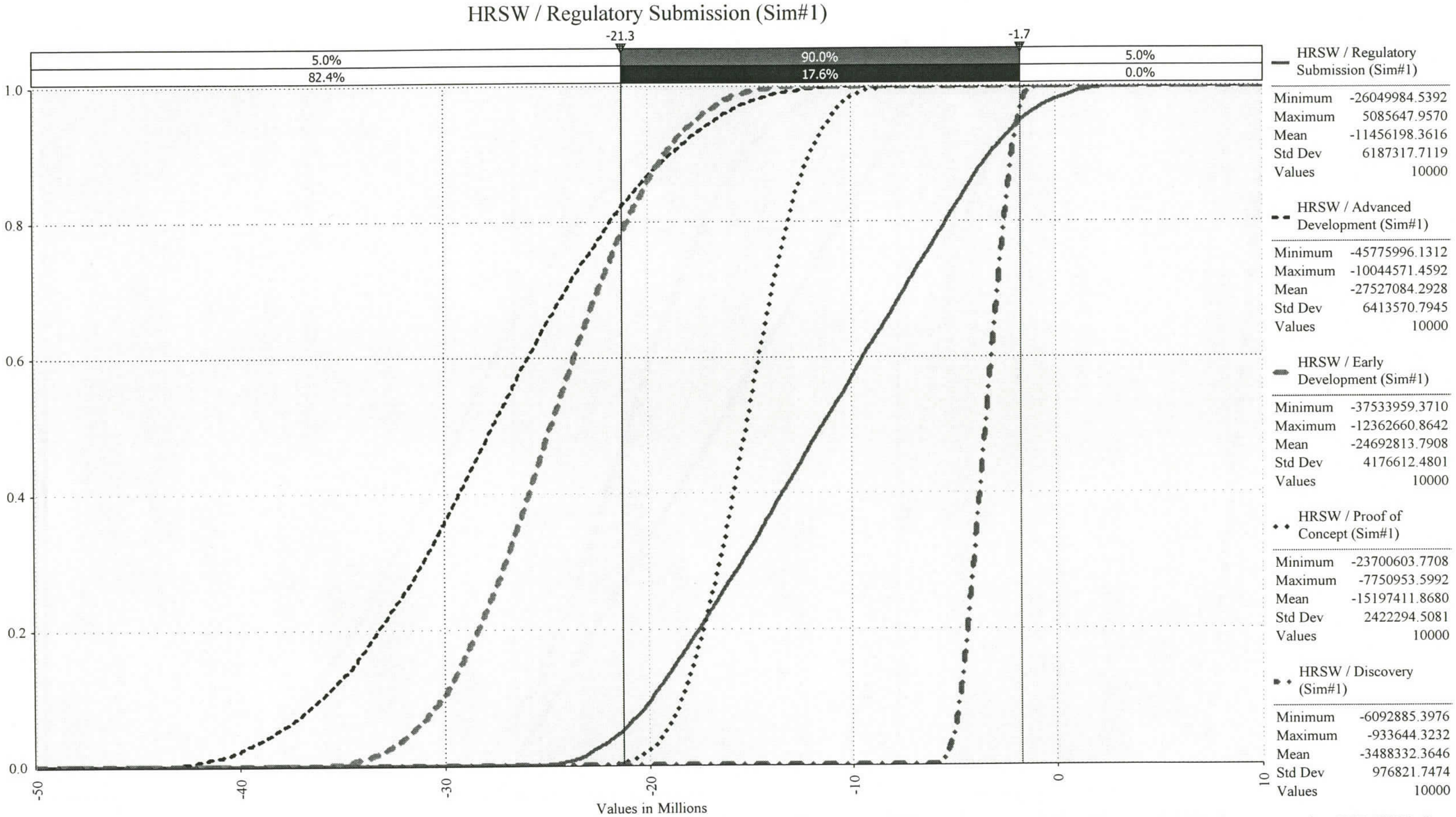


Figure C.9. Ascending Cumulative Distribution for Option Values Across Stages of Development for Drought Tolerance in HRSW for Acreage in United States ($ in billions, c=.5).

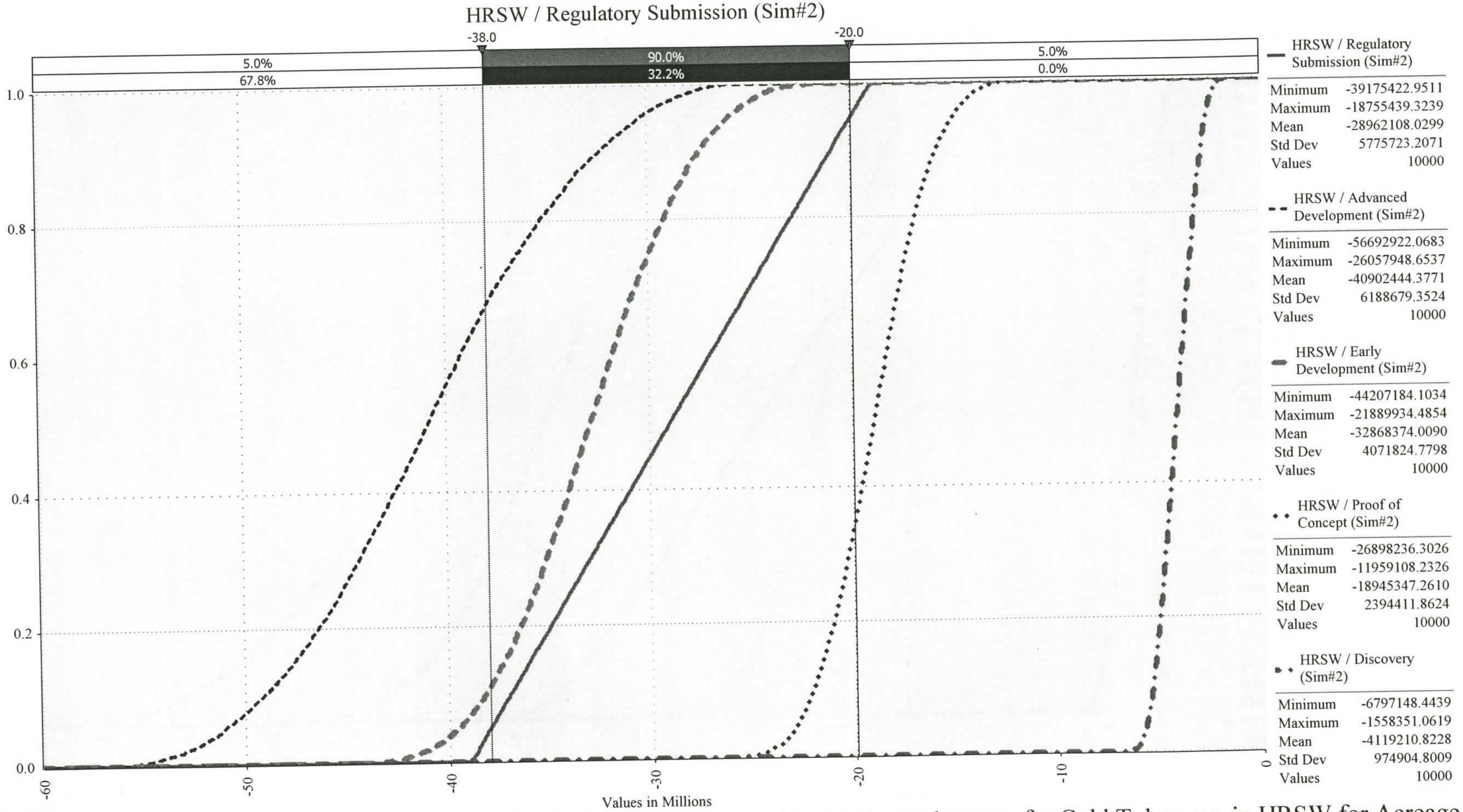


Figure C.10. Ascending Cumulative Distribution for Option Values Across Stages of Development for Cold Tolerance in HRSW for Acreage in United States ($ in billions, c=.5).

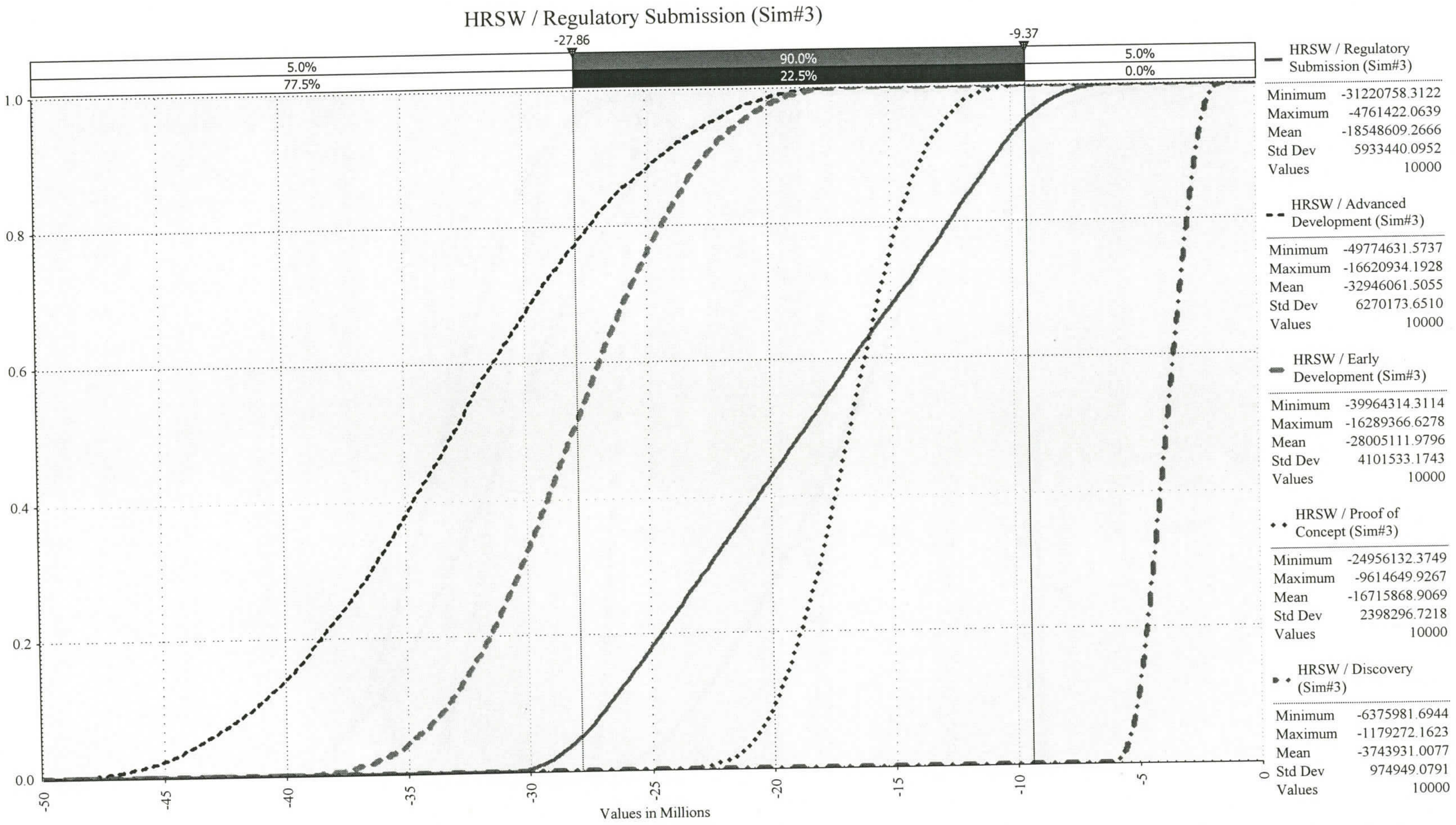


Figure C.11. Ascending Cumulative Distribution for Option Values Across Stages of Development for NUE in HRSW for Acreage in United States ($ in billions, c=.5).

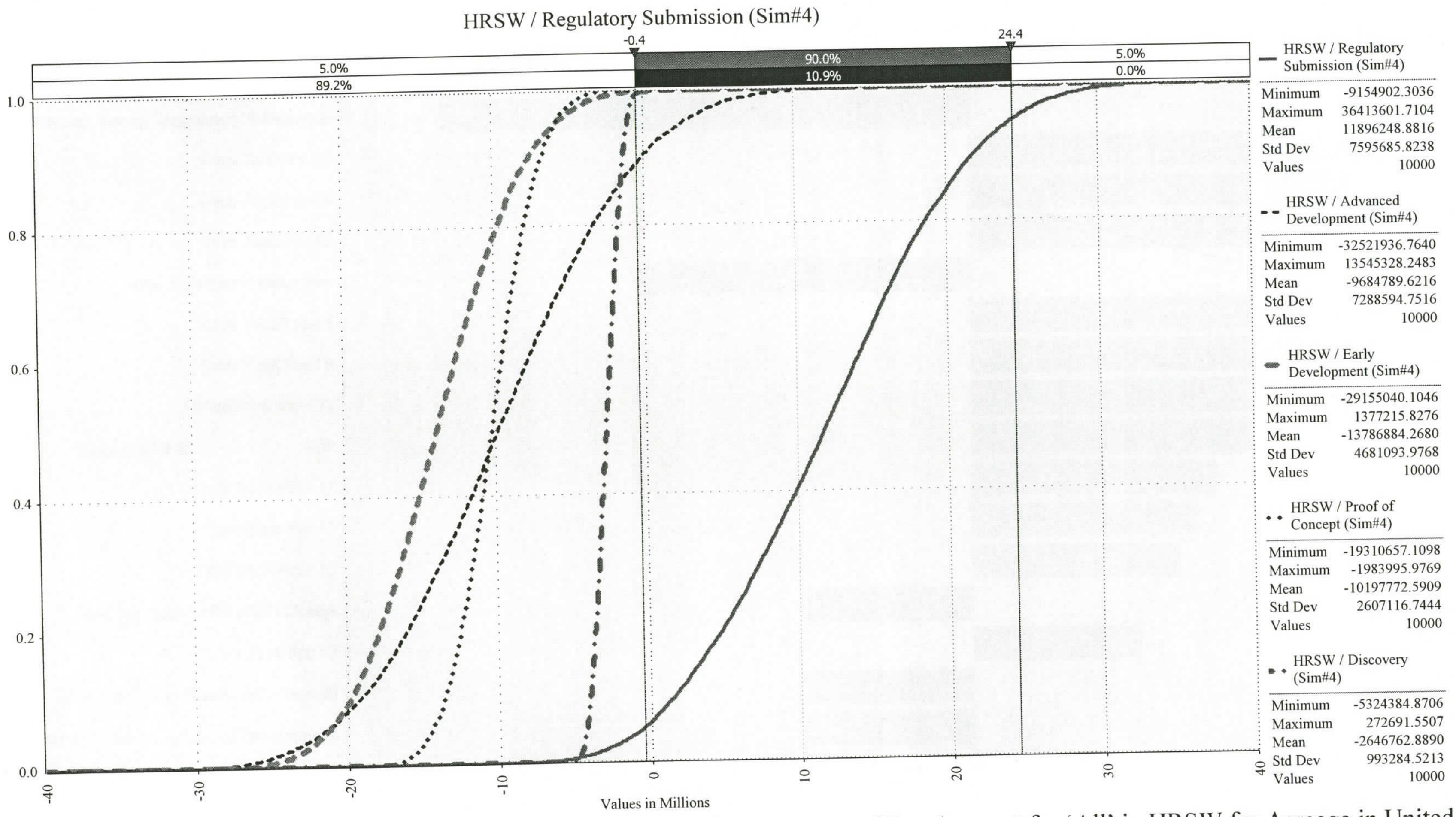


Figure C.12. Ascending Cumulative Distribution for Option Values Across Stages of Development for ‘All’ in HRSW for Acreage in United States ($ in billions, c=.5).

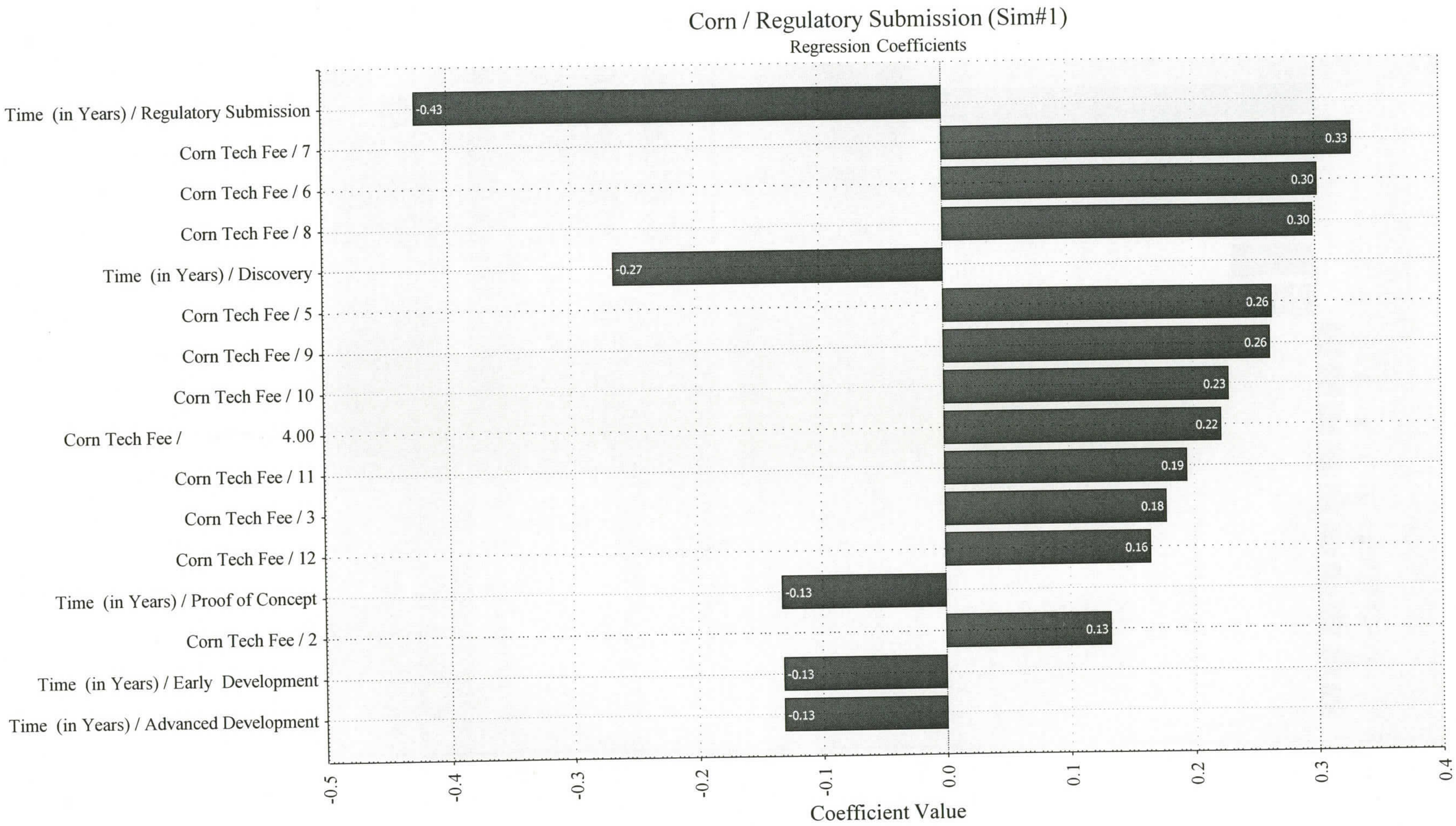


Figure C.13. Tornado Graph Showing Regression Coefficients for Drought Tolerance During Regulatory Submission in Corn for Acreage in United States ($ in billions, c=.5).

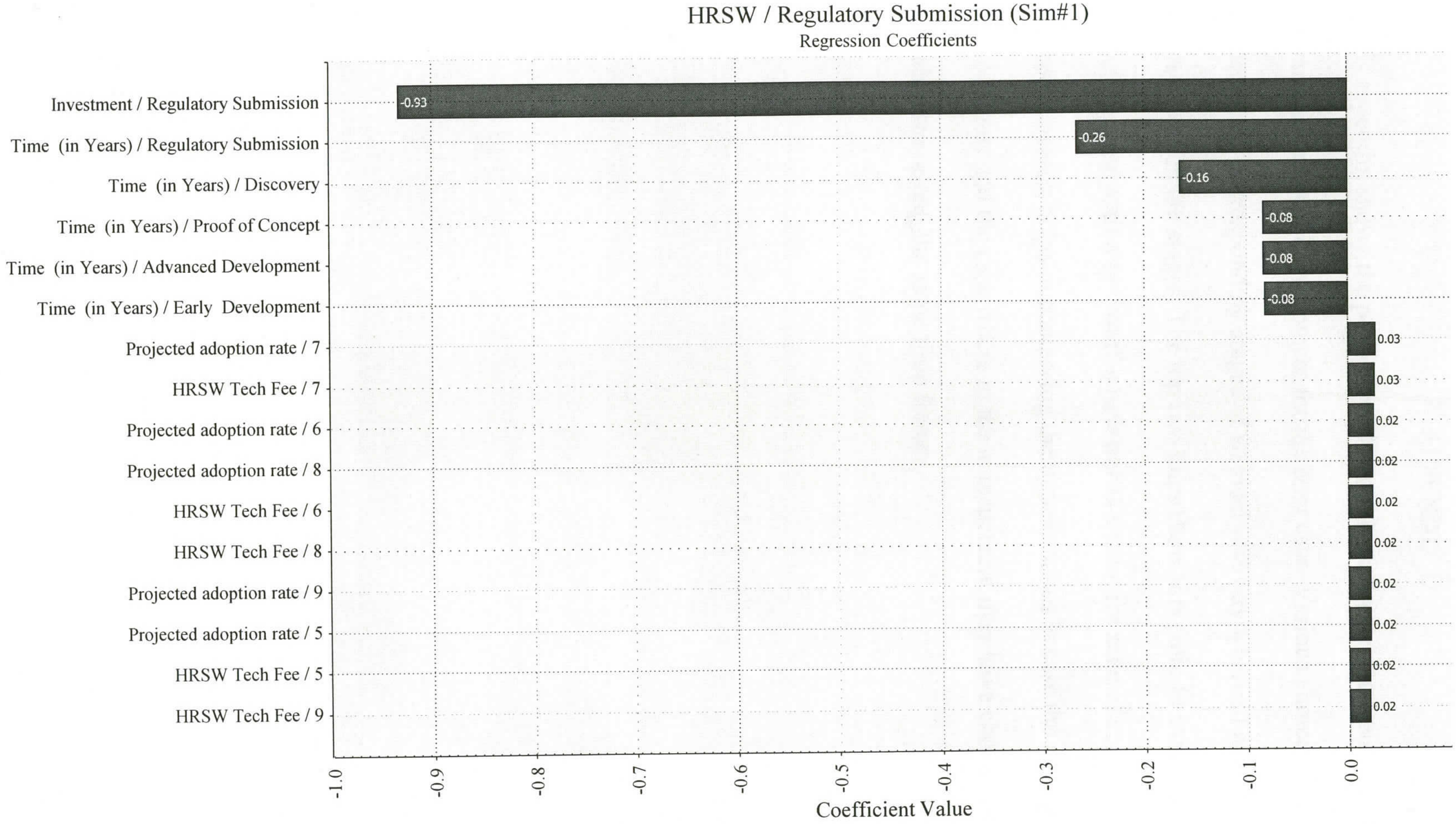


Figure C.14. Tornado Graph Showing Regression Coefficients for Drought Tolerance During Regulatory Submission in HRSW for Acreage in United States ($ in billions, c=.5).

APPENDIX D

This appendix shows the possible pathways that management can take, and option values at various stages of development for the base case. Various choices that can be made are presented under corresponding stages of an ideal pathway where in option to “continue” has been chosen at all the stages. The top two lines show this path. In case the management decides to choose the option to “wait” a new tree is shown for sake of comparison. This pictorial representation helps in comparing the option values in case the management decides to continue and the case where in the management may have chosen either option to wait or abandon, along the same time frame.

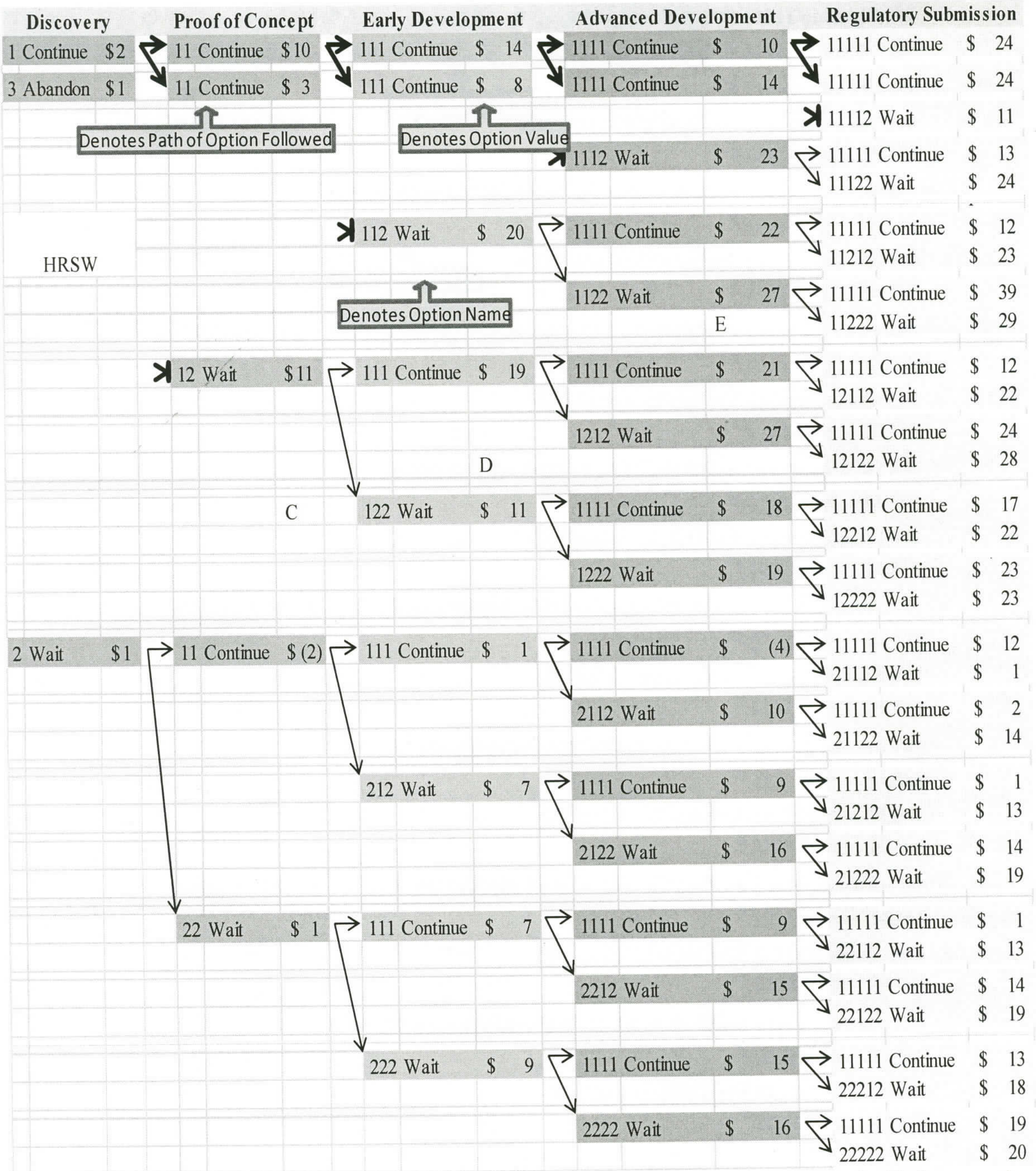


Figure D.1. Trees Showing Possible Pathways and Option Values of Drought Tolerance in HRSW on relative scale. (1=Continue,2=Wait, 3=Abandon) for Acreage in United States ($ in millions, c=.5).

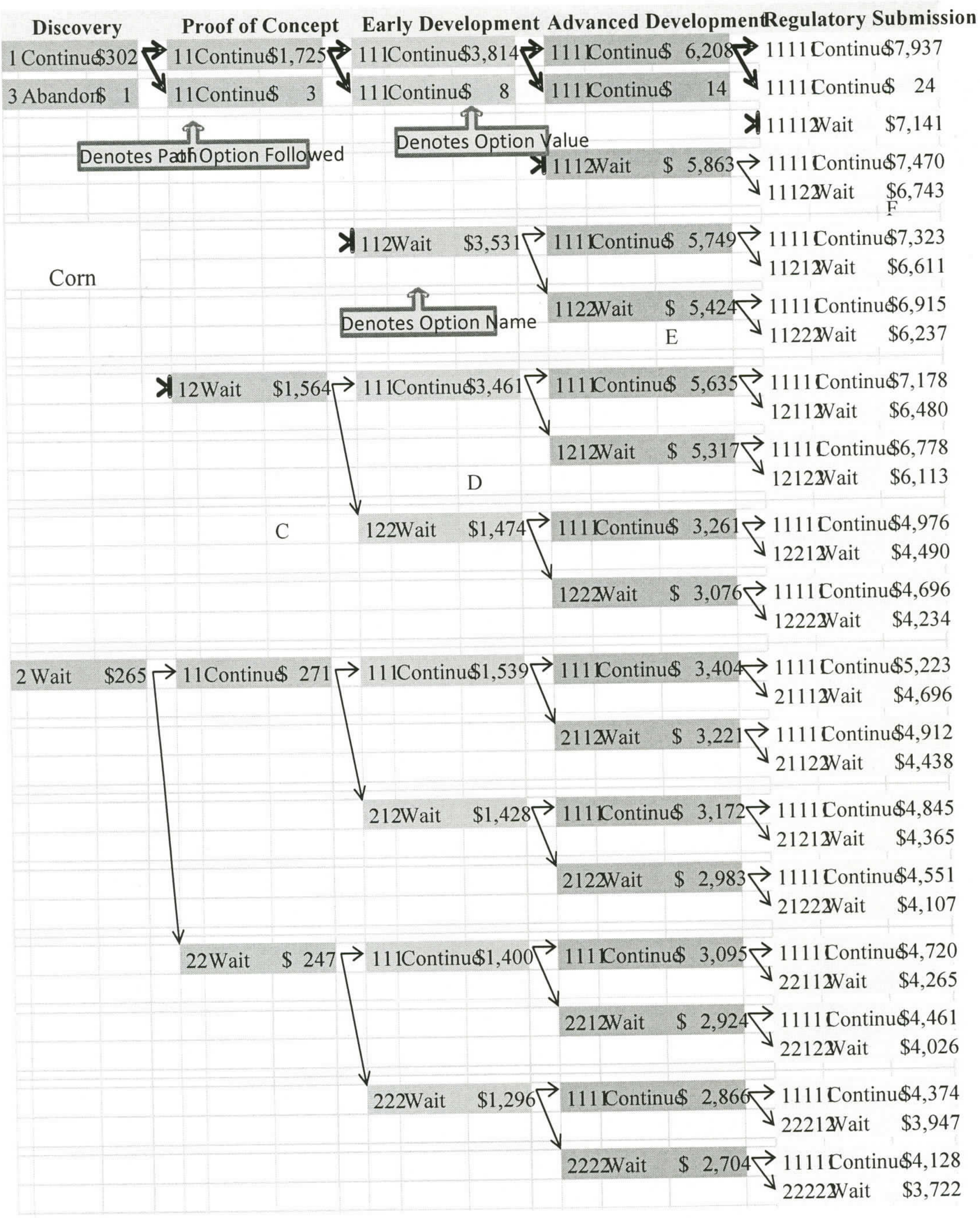


Figure D.2. Trees Showing Possible Pathways and Option Values of Drought Tolerance in Corn on relative scale. (1=Continue,2=Wait, 3=Abandon) for Acreage in United States ($ in millions, c=.5).

APPENDIX E

This appendix shows the probability distribution curves for traits at various stages of development for base case of planted acreage of United States and technology fee share of 50%.

Corn: Base Case

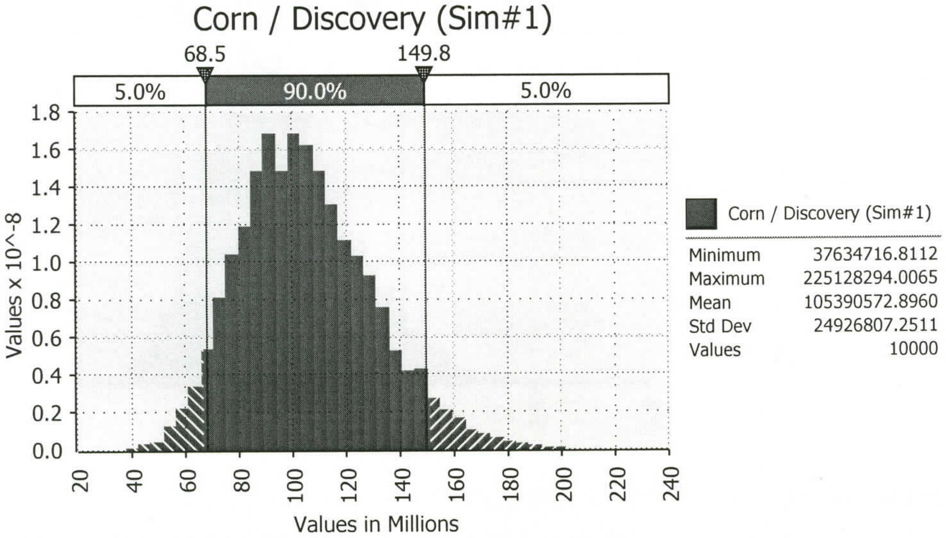


Figure E.1. Probability Distribution of Option values for Drought resistance in Corn in Discovery Phase for Acreage in United States at c=0.5.

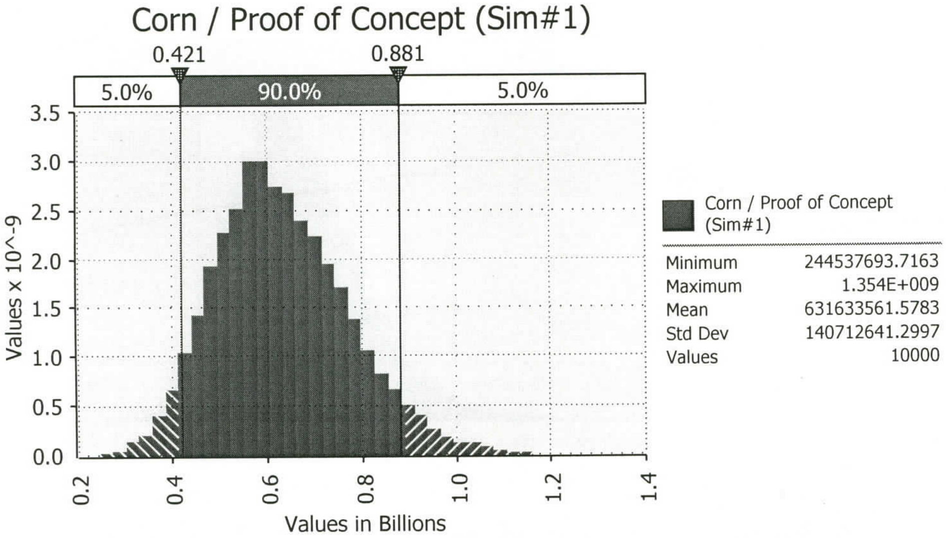


Figure E.2. Probability Distribution of Option values for Drought resistance in Corn in Proof of Concept Phase for Acreage in United States at c=0.5.

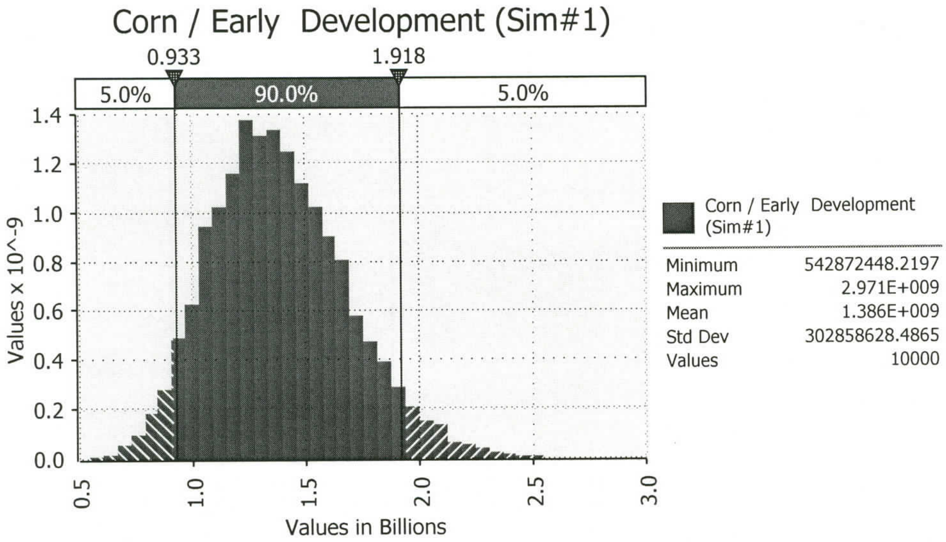


Figure E.3. Probability Distribution of Option values for Drought resistance in Corn in Early Development Phase for Acreage in United States at c=0.5.

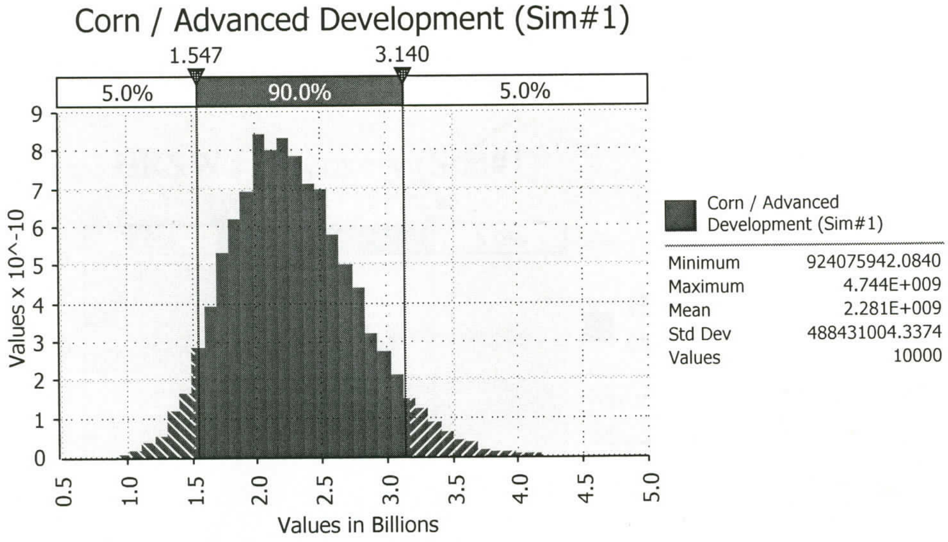
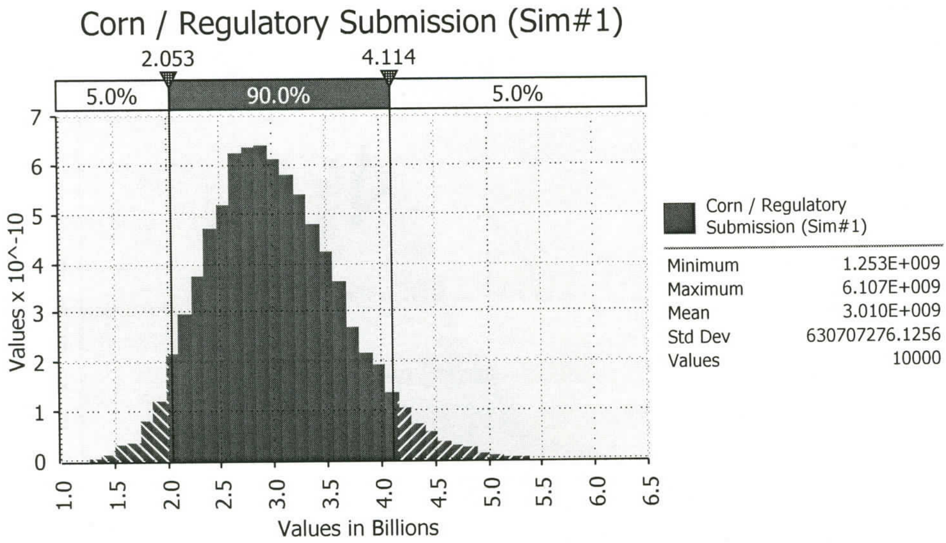


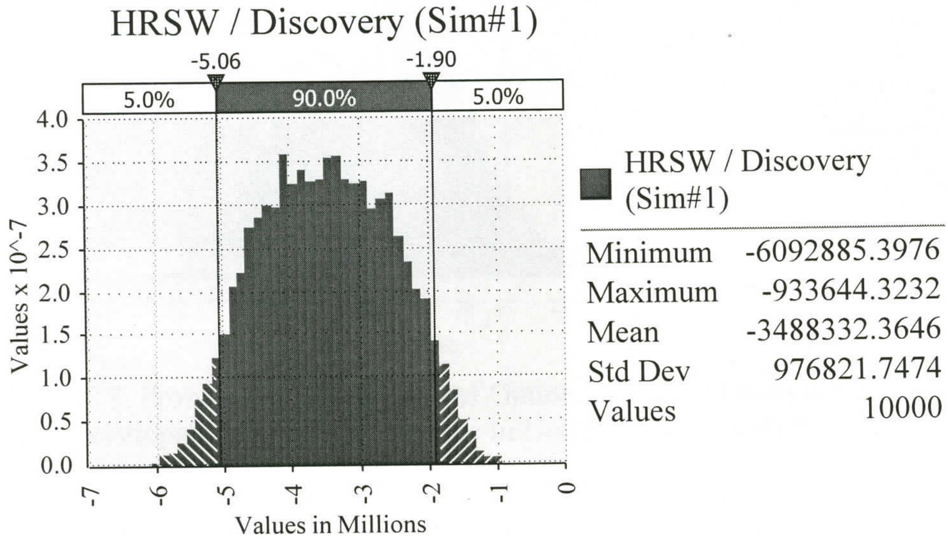
Figure E.4. Probability Distribution of Option values for Drought resistance in Corn in Advanced Development Phase for Acreage in United States at c=0.5.



Minimum	1.253E+009
Maximum	6.107E+009
Mean	3.010E+009
Std Dev	630707276.1256
Values	10000

Figure E.5. Probability Distribution of Option values for Drought resistance in Corn in Regulatory Submission Phase for Acreage in United States at c=0.5.

HRSW: Base Case



Minimum	-6092885.3976
Maximum	-933644.3232
Mean	-3488332.3646
Std Dev	976821.7474
Values	10000

Figure E.6. Probability Distribution of Option values for Drought resistance in HRSW in Discovery Phase for Acreage in United States at c=0.5.

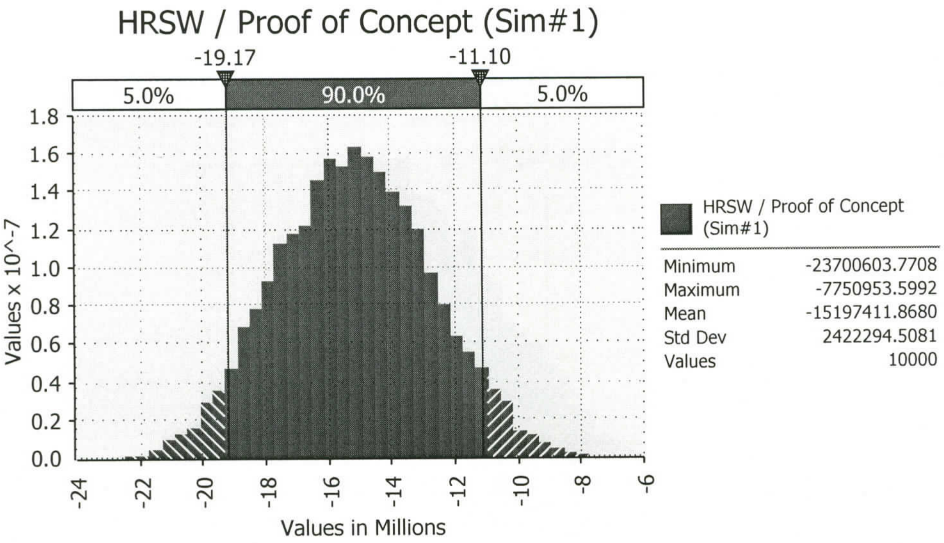


Figure E.7. Probability Distribution of Option values for Drought resistance in HRSW in Proof of Concept Phase for Acreage in United States at c=0.5.

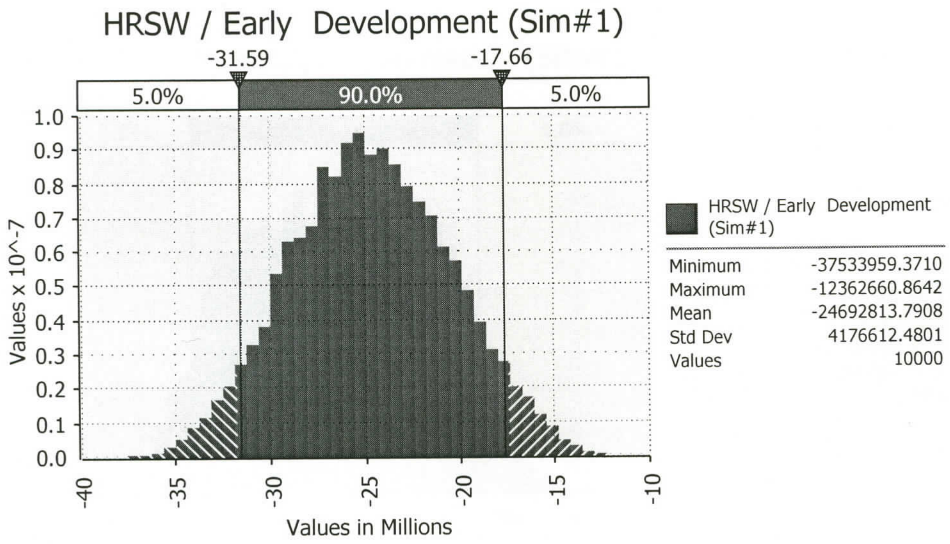


Figure E.8. Probability Distribution of Option values for Drought resistance in HRSW in Early Development Phase for Acreage in United States at c=0.5.

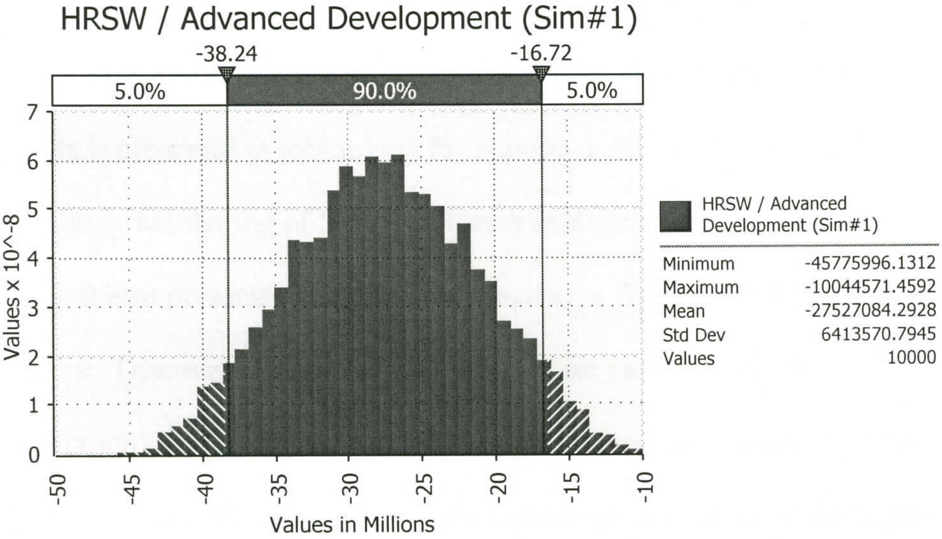


Figure E.9. Probability Distribution of Option values for Drought resistance in HRSW in Advanced Development Phase for Acreage in United States at c=0.5.

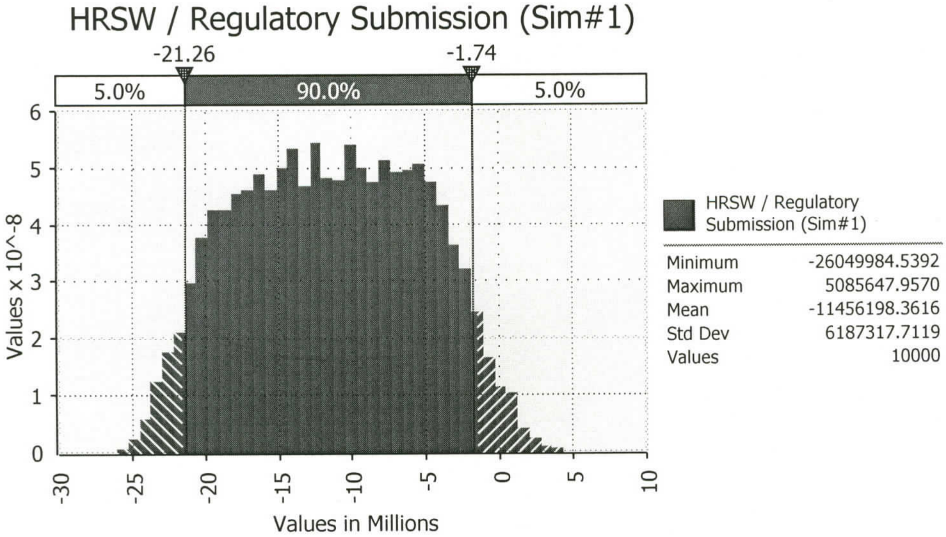


Figure E.10. Probability Distribution of Option values for Drought resistance in HRSW in Regulatory Submission Phase for Acreage in United States at c=0.5.

APPENDIX F

This appendix presents sensitivity results. The combined acreage of U.S. and Canada is presented at technology fee sharing at 30, 40, 50, 60, and 70%. In base case, technology fee sharing of 50% for planted acreage of U.S. was considered.

It also presents the ascending cumulative distribution for option values across GM traits for "Discovery" and Regulatory" stage for various traits. Steeper curve represents lesser range of risk. Curves to the left represent less risky compare to those to the right. Also presented in this appendix are the tornado graphs showing the regression coefficients for traits.

The sensitivity results in order of traits for corn and HRSW.

Corn & HRSW: Sensitivity Planted Acres (Technology Fee Same As In Base Case)

(Combined Acreage of United States and Canada at c=0.5)

Table F.1. Minimum, Mean, and Maximum Option Values for Drought Tolerance in Crops for Combined Acreage of US & Canada. ($ in millions, c=.5).

Drought Tolerance ($ in millions)					
Corn	Discovery	Proof of Concept	Early Development	Advanced Development	Regulatory Submission
Min	41.03	259.59	568.09	913.63	1218.37
Mean	105.39	631.69	1386.39	2281.20	3010.34
Max	236.85	1346.53	2875.86	4737.93	6054.99
HRSW					
Min	(5.33)	(17.10)	(25.59)	(28.10)	(3.80)
Mean	(2.44)	(8.99)	(11.15)	(5.38)	17.54
Max	0.66	0.86	5.99	22.08	44.99

Table F.2. Minimum, Mean, and Maximum Option Values for Cold Tolerance in Crops for Combined Acreage of US & Canada. ($ in millions, c=.5).

Cold Tolerance					
Corn	Discovery	Proof of Concept	Early Development	Advanced Development	Regulatory Submission
Min	31.15	203.06	461.86	759.75	1018.01
Mean	78.36	471.08	1036.05	1707.99	2260.09
Max	172.54	981.27	2098.56	3460.02	4428.13
HRSW					
Min	(6.83)	(26.21)	(43.69)	(55.48)	(37.94)
Mean	(4.06)	(18.60)	(32.11)	(39.66)	(27.34)
Max	(1.33)	(11.12)	(20.90)	(24.36)	(16.49)

Table F.3. Minimum, Mean, and Maximum Option Values for NUE in Crops for Combined Acreage of US & Canada. ($ in millions, c=.5).

Nitrogen Use Efficiency (NUE)					
Corn	Discovery	Proof of Concept	Early Development	Advanced Development	Regulatory Submission
Min	39.20	251.43	563.00	905.51	1207.80
Mean	98.86	592.91	1301.79	2142.79	2829.18
Max	219.60	1248.53	2667.32	4395.07	5618.51
HRSW					
Min	(5.92)	(20.57)	(32.20)	(38.56)	(18.05)
Mean	(3.10)	(12.88)	(19.64)	(19.27)	(0.64)
Max	(0.30)	(5.09)	(6.20)	3.05	19.13

Table F.4. Minimum, Mean, and Maximum Option Values for 'All' in Crops for Combined Acreage of US & Canada. ($ in millions, c=.5).

ALL					
Corn	Discovery	Proof of Concept	Early Development	Advanced Development	Regulatory Submission
Min	45.24	289.06	654.53	1051.27	1397.59
Mean	111.58	668.46	1466.60	2412.44	3182.11
Max	245.48	1395.53	2980.15	4909.37	6273.24
HRSW					
Min	(3.61)	(7.44)	(4.82)	5.79	39.99
Mean	(0.29)	3.83	16.80	40.36	77.40
Max	3.90	19.27	47.21	86.75	129.59

Corn: Sensitivity Planted Acres (Technology Fee Same as in Base Case).

(Combined Acreage of United States and Canada at c=0.5)

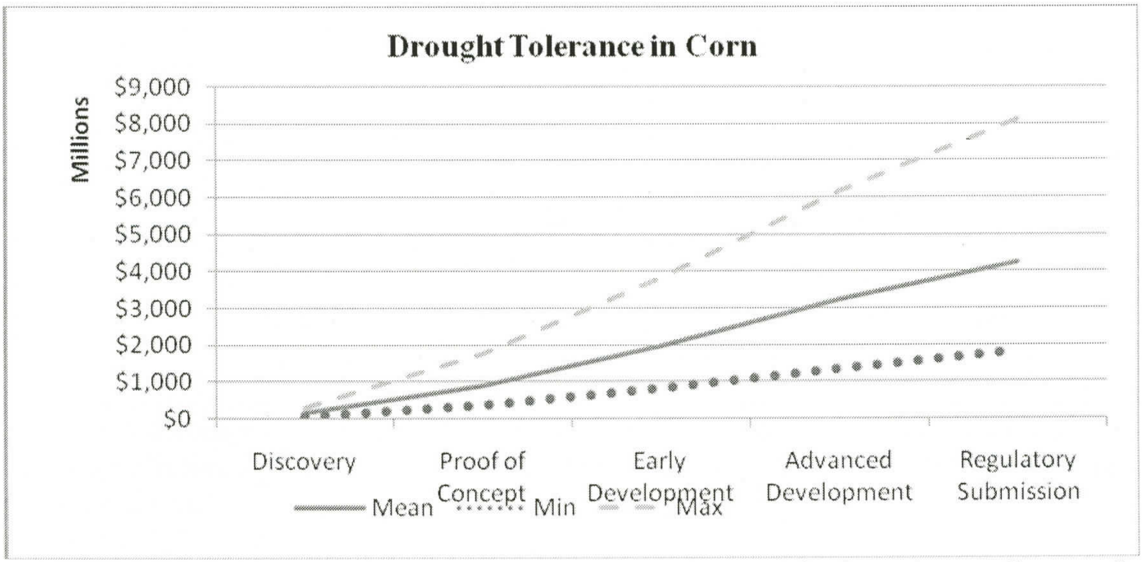


Figure F.1. Change in Option Values of 'Drought Tolerance' in Corn Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.5).

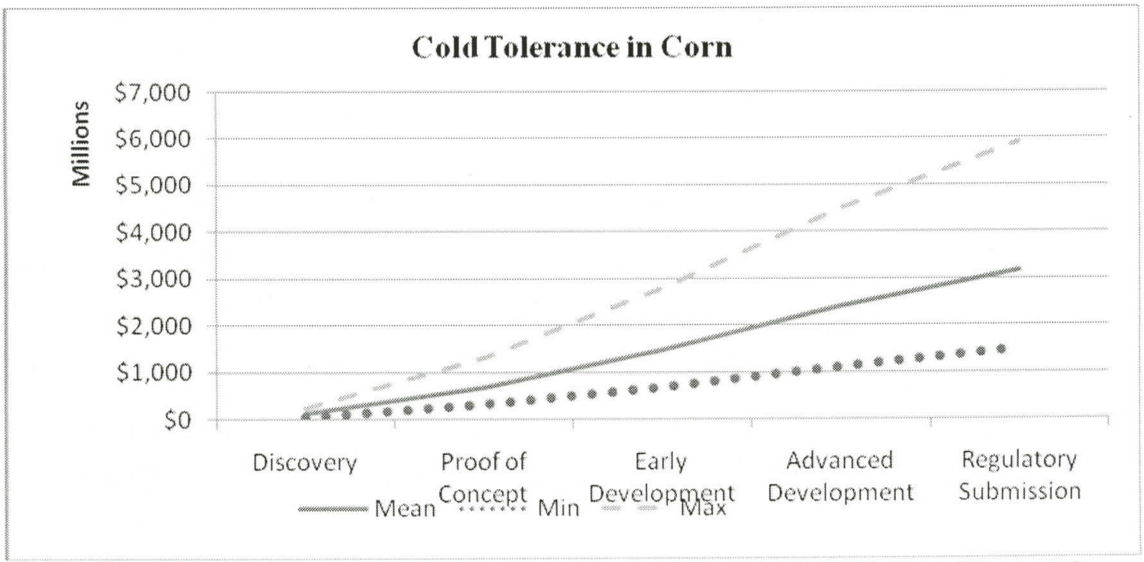


Figure F.2. Change in Option Values of 'Cold Tolerance' in Corn Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.5).

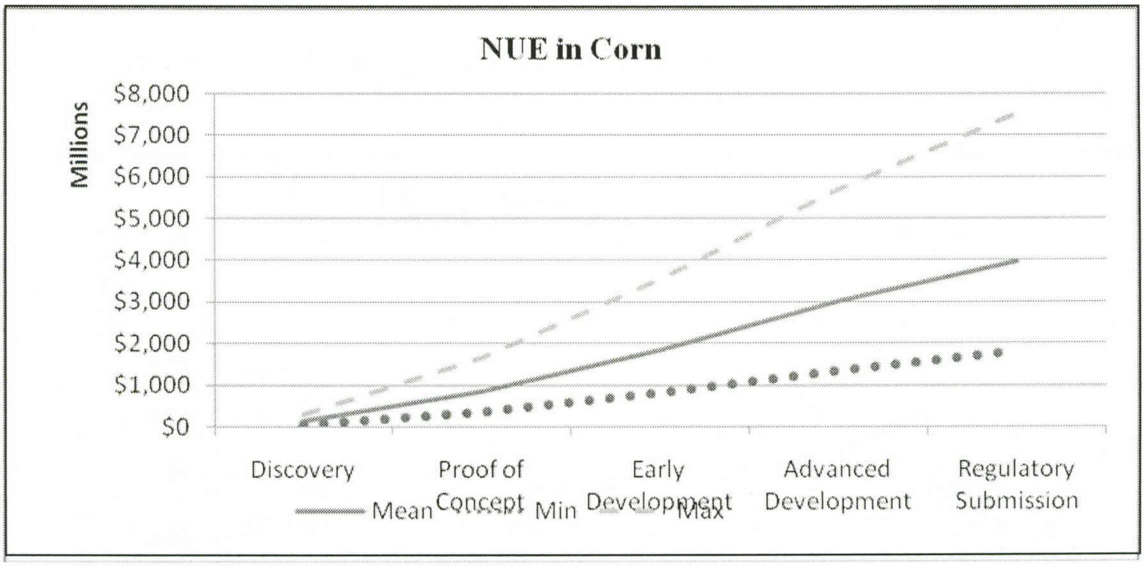


Figure F.3. Change in Option Values of 'NUE' in Corn Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.5).

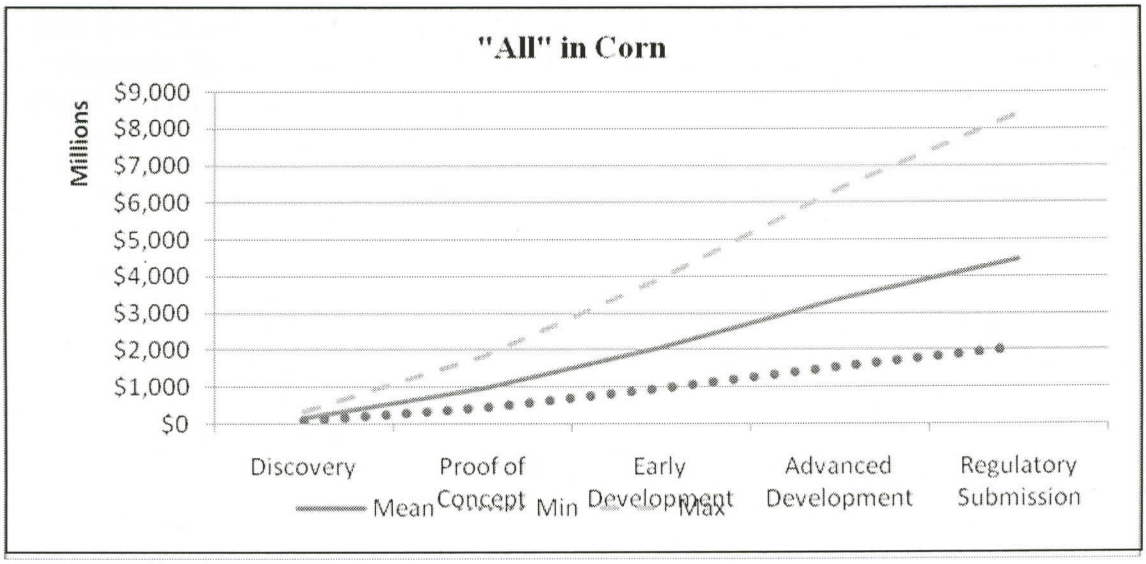


Figure F.4. Change in Option Values of 'All' in Corn Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.5).

HRSW: Sensitivity Planted Acres (Technology Fee Same as in Base Case).

(Combined Acreage of United States and Canada at c=0.5)

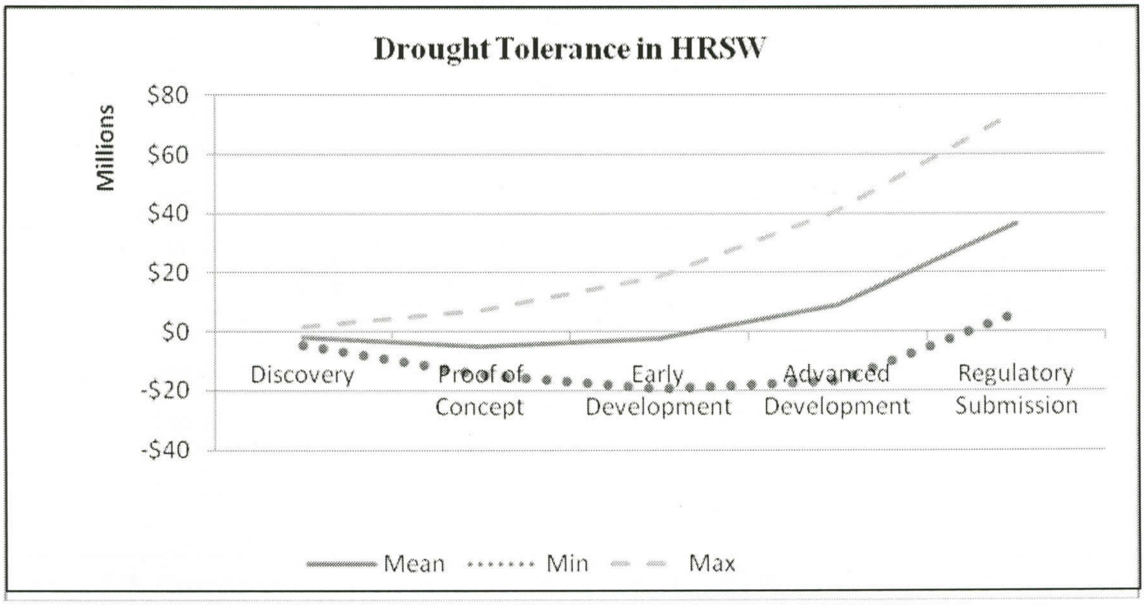


Figure F.5. Change in Option Values of 'Drought Tolerance' in HRSW Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.5).

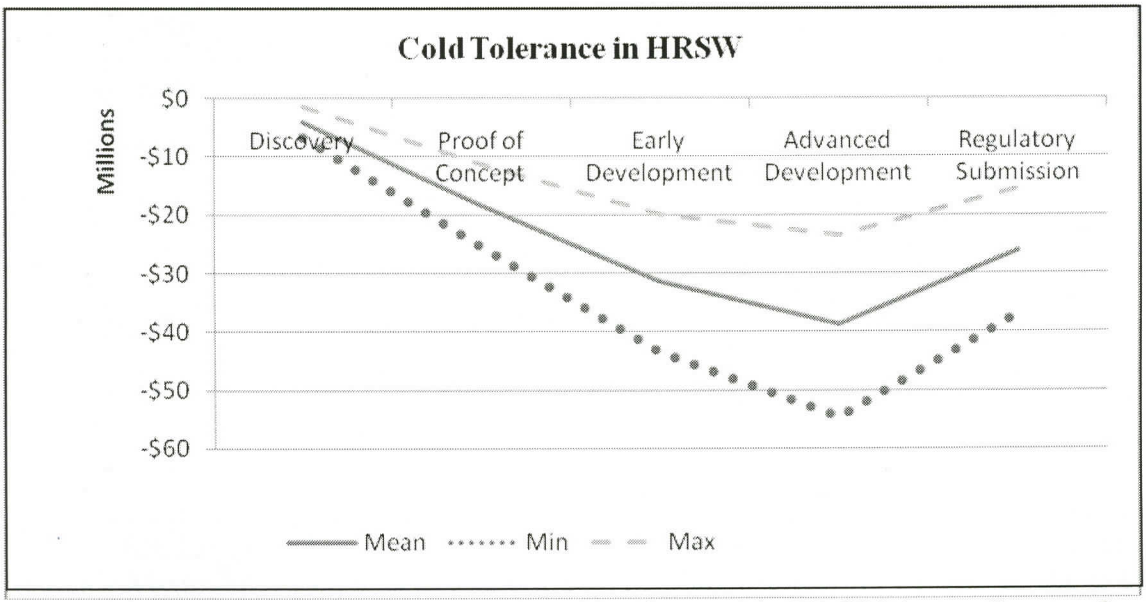


Figure F.6. Change in Option Values of 'Cold Tolerance' in HRSW Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.5)6

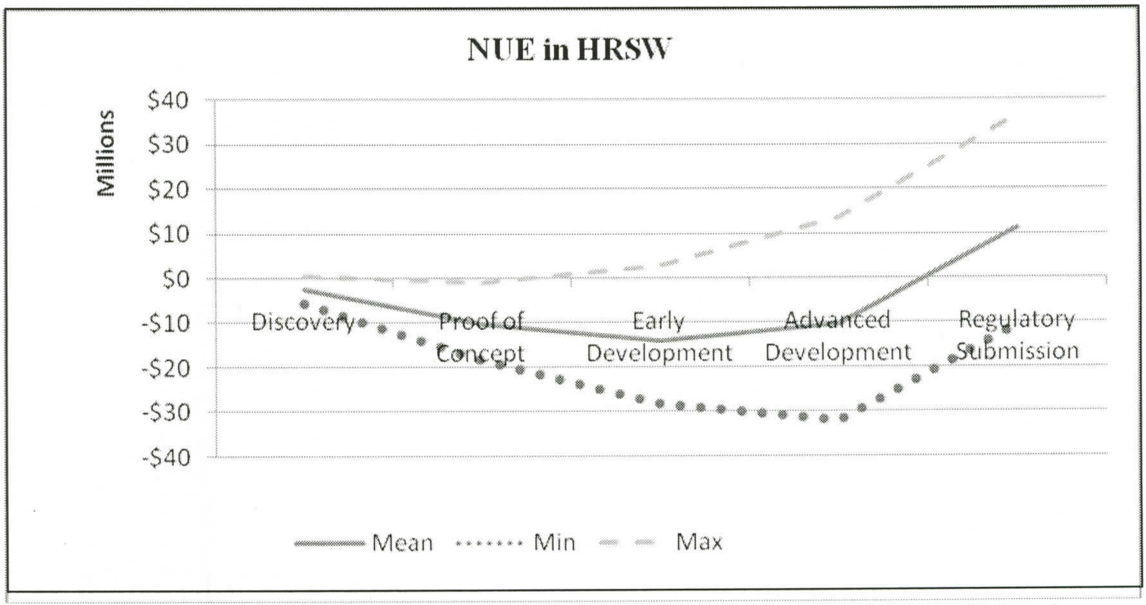


Figure F.7. Change in Option Values of 'NUE' in HRSW Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.5).

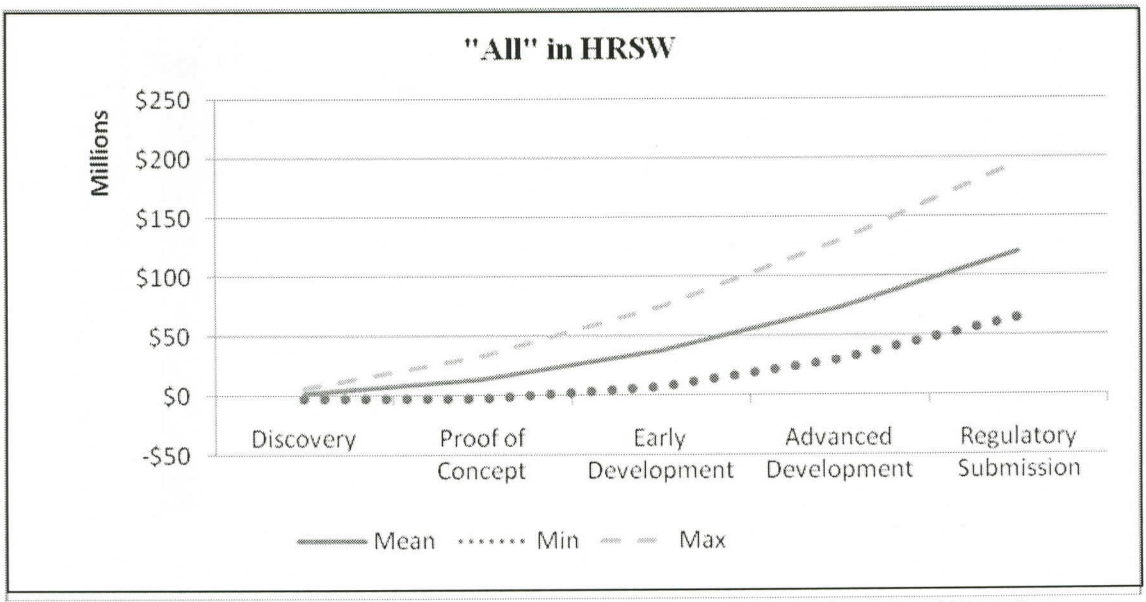


Figure F.8. Change in Option Values of 'All' in HRSW Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.5).

Sensitivity Planted Acres For Corn (Combined Acreage of United States and Canada at c=0.5)

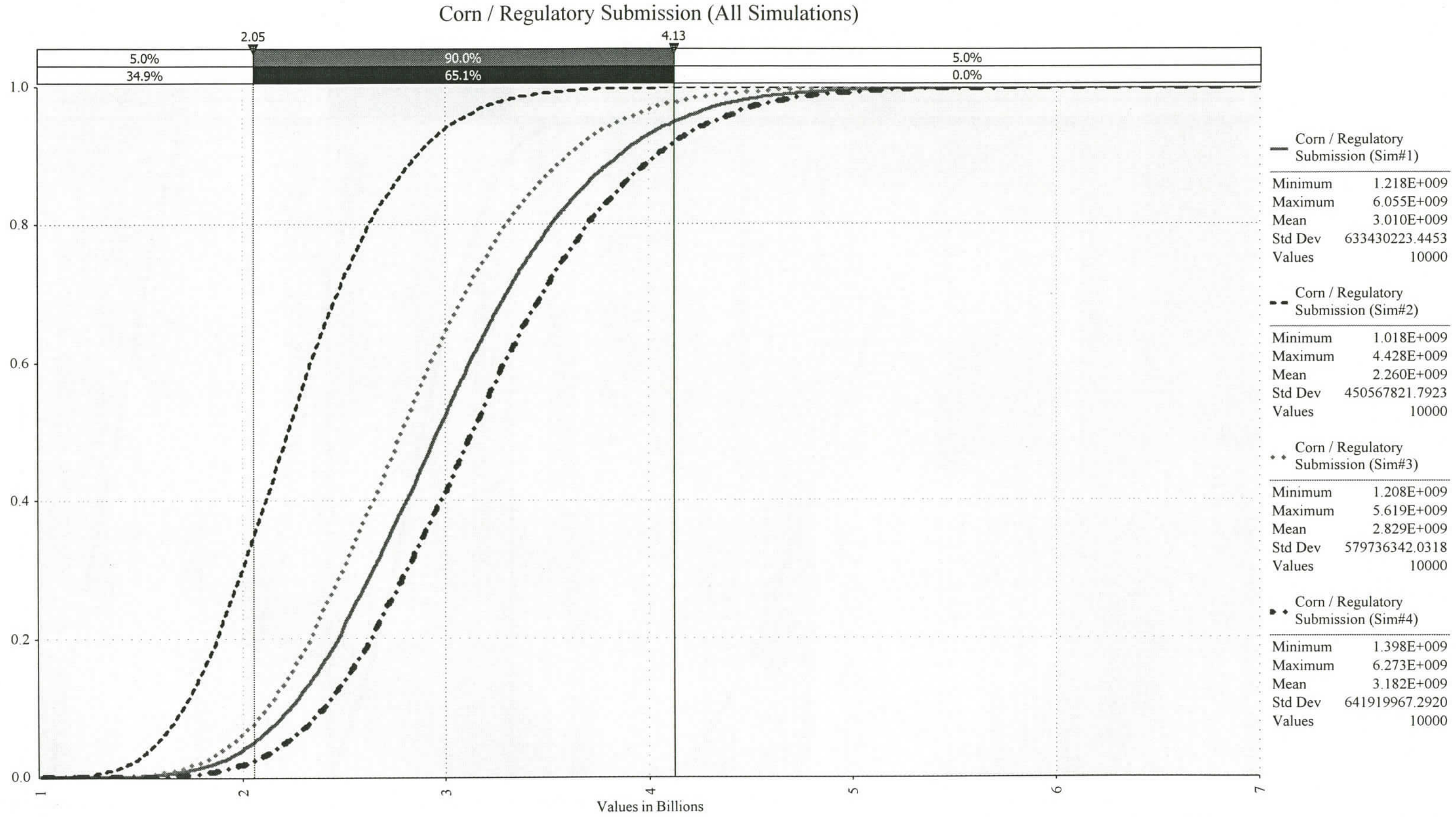


Figure F.9. Cumulative Distribution for Option Values Across GM Traits at Regulatory Submission in Corn (Sim#1=Drought, Sim#2=Cold, Sim#3=NUE,Sim#4='All") for Combined Acreage in United States and Canada($ in millions, c=.5).

Sensitivity Planted Acres For HRSW (Combined Acreage of United States and Canada at c=0.5)

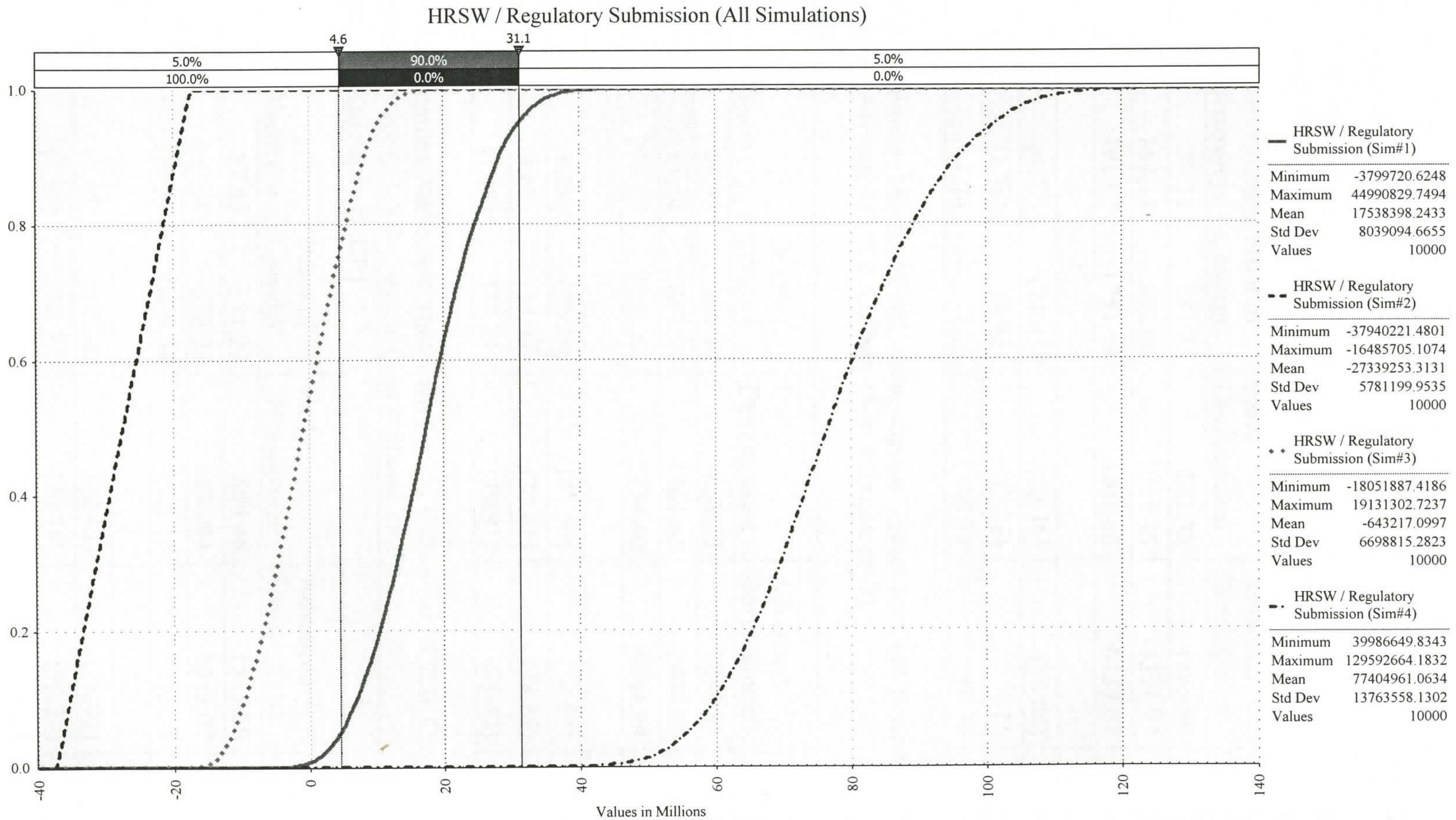


Figure F.10. Cumulative Distribution for Option Values Across GM Traits at Regulatory Submission in HRSW (Sim#1=Drought, Sim#2=Cold, Sim#3=NUE,Sim#4='All") for Combined Acreage in United States and Canada($ in millions, c=.5).

Sensitivity Planted Acres (Higher Share Of Technology Fee)

(Combined Acreage of United States and Canada at c=0.7)

Table F.5. Minimum, Mean, and Maximum Option Values for Drought Tolerance in Crops for Combined Acreage of US & Canada. ($ in millions, c=.7).

Drought Tolerance ($ in millions)					
Corn	Discovery	Proof of Concept	Early Development	Advanced Development	Regulatory Submission
Min	59.21	381.75	831.95	1363.90	1838.58
Mean	149.31	892.60	1955.45	3211.97	4228.31
Max	301.67	1757.68	3801.60	6139.63	8100.59
HRSW					
Min	(4.71)	(14.45)	(19.45)	(16.86)	5.94
Mean	(1.76)	(4.92)	(2.26)	9.16	36.57
Max	1.74	7.26	18.73	40.76	74.04

Table F.6. Minimum, Mean, and Maximum Option Values for Cold Tolerance in Crops for Combined Acreage of US & Canada. ($ in millions, c=.7).

Cold Tolerance					
Corn	Discovery	Proof of Concept	Early Development	Advanced Development	Regulatory Submission
Min	46.90	304.99	667.20	1095.81	1482.12
Mean	111.44	667.59	1464.65	2409.02	3177.43
Max	219.47	1281.64	2774.40	4484.04	5922.32
HRSW					
Min	(6.69)	(25.55)	(43.50)	(54.62)	(37.05)
Mean	(4.02)	(18.37)	(31.61)	(38.85)	(26.27)
Max	(1.34)	(11.21)	(19.91)	(23.42)	(15.37)

Table F.7. Minimum, Mean, and Maximum Option Values for NUE in Crops for Combined Acreage of US & Canada. ($ in millions, c=.7).

Nitrogen Use Efficiency (NUE)					
Corn	Discovery	Proof of Concept	Early Development	Advanced Development	Regulatory Submission
Min	57.53	371.27	809.46	1327.30	1789.92
Mean	140.16	838.26	1836.93	3018.07	3974.53
Max	279.55	1629.54	3525.10	5693.98	7514.24
HRSW					
Min	(5.48)	(18.28)	(28.12)	(31.92)	(10.50)
Mean	(2.68)	(10.37)	(14.16)	(10.29)	11.11
Max	0.43	(0.89)	2.82	13.63	36.48

Table F.8. Minimum, Mean, and Maximum Option Values for 'All' in Crops for Combined Acreage of US & Canada. ($ in millions, c=.7).

ALL					
Corn	Discovery	Proof of Concept	Early Development	Advanced Development	Regulatory Submission
Min	66.60	427.90	931.00	1525.05	2052.86
Mean	157.98	944.10	2067.78	3395.74	4468.82
Max	312.44	1820.04	3936.17	6356.53	8385.96
HRSW					
Min	(2.54)	(2.66)	7.35	29.30	64.38
Mean	1.26	13.03	36.89	73.21	120.39
Max	6.23	33.23	75.22	129.82	195.37

Corn: Sensitivity Planted Acres (Higher Technology Fee).

(Combined Acreage of United States and Canada at c=0.7)

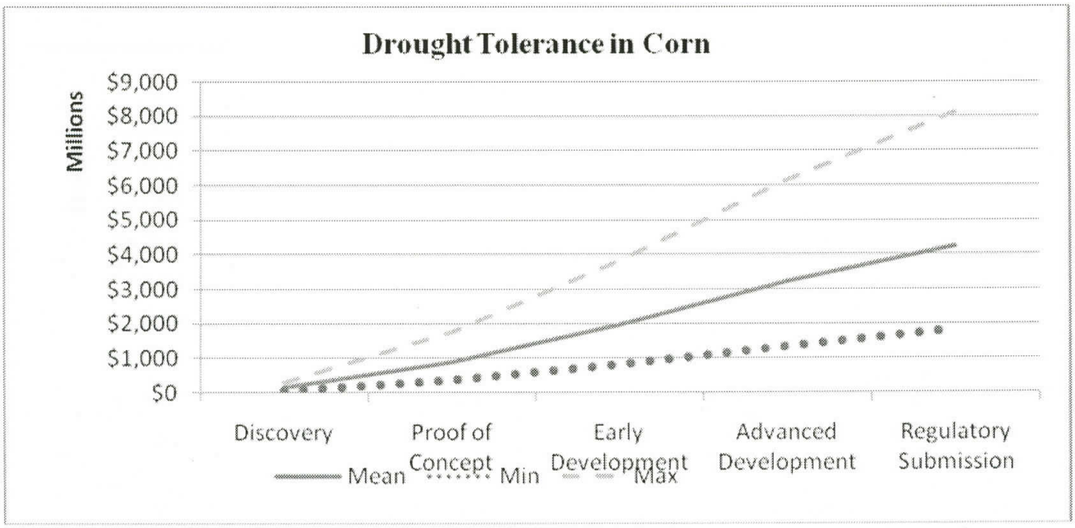


Figure F.11. Change in Option Values of 'Drought Tolerance' in Corn Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.7).

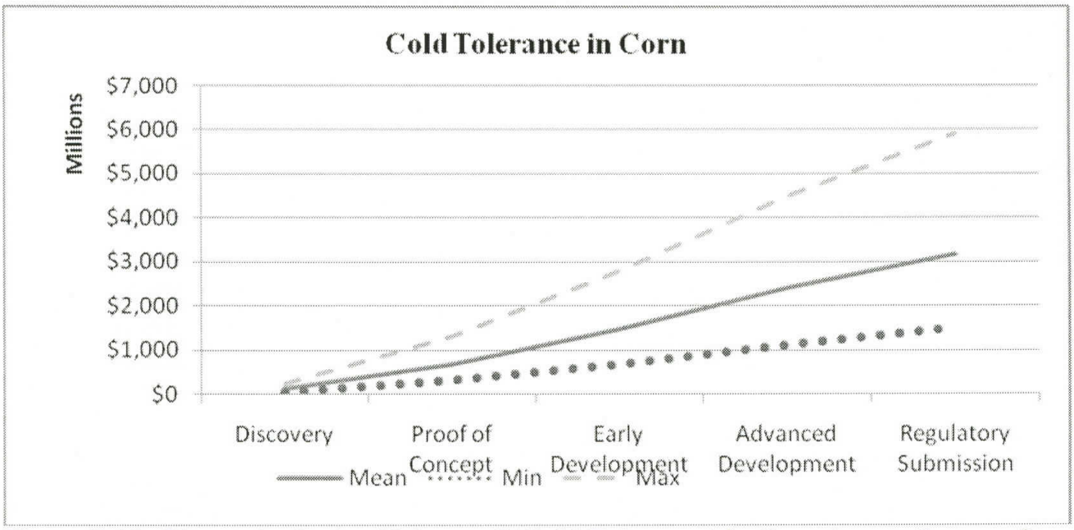


Figure F.12. Change in Option Values of 'Cold Tolerance' in Corn Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.7).

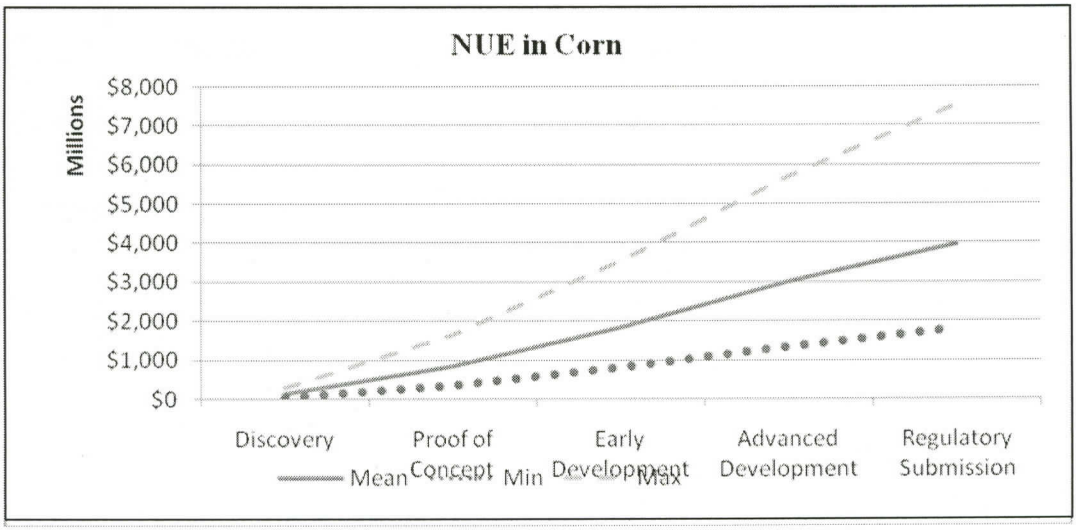


Figure F.13. Change in Option Values of 'NUE' in Corn Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.7).

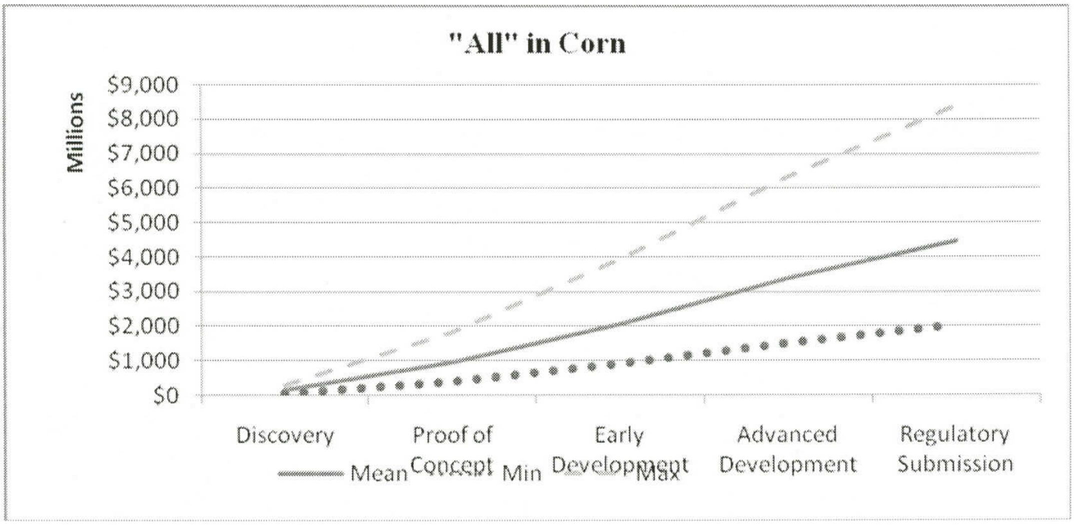


Figure F.14. Change in Option Values of 'All' in Corn Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.7).

HRSW: Sensitivity Planted Acres (Higher Technology Fee).

(Combined Acreage of United States and Canada at c=0.7)

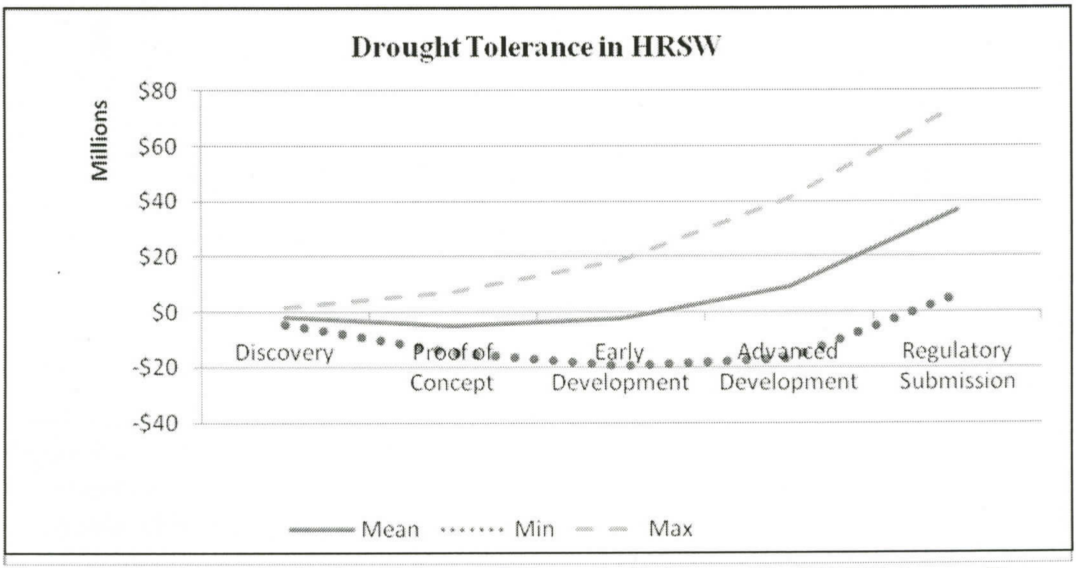


Figure F.15. Change in Option Values of 'Drought Tolerance' in HRSW Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.7).

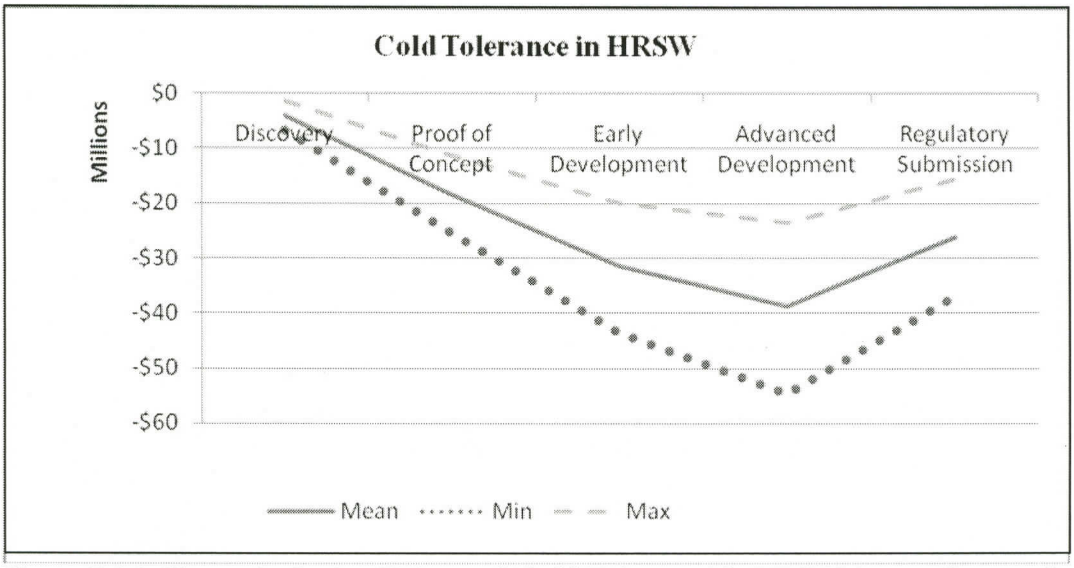


Figure F.16. Change in Option Values of 'Cold Tolerance' in HRSW Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.7).

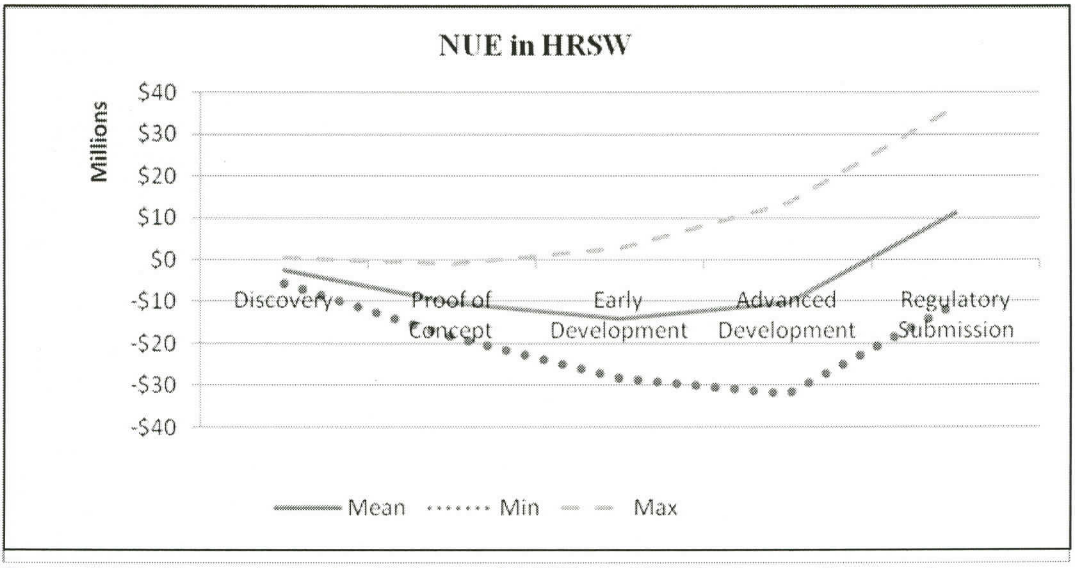


Figure F.17. Change in Option Values of 'NUE' in HRSW Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.7).

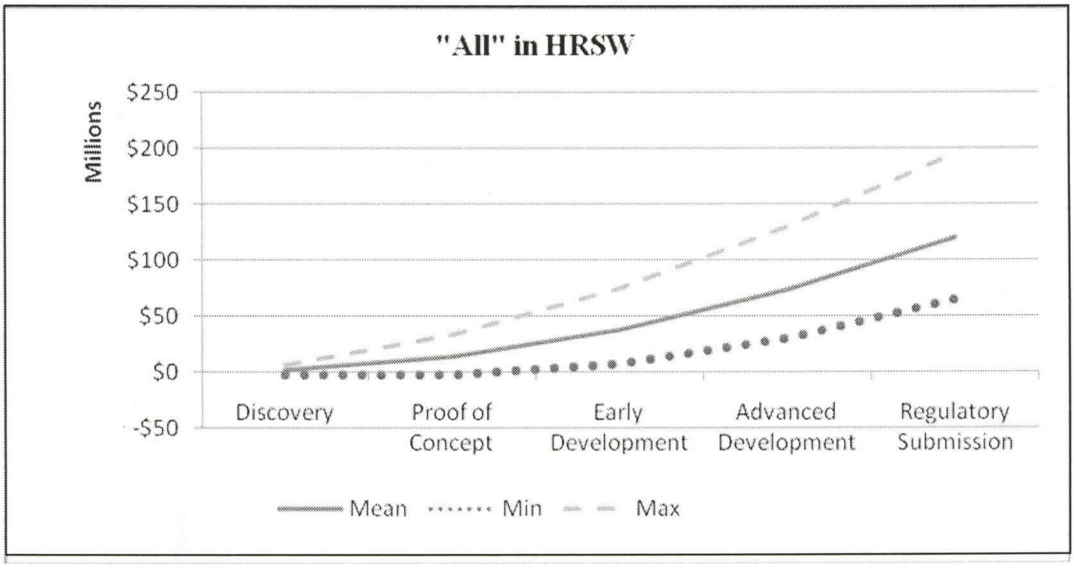


Figure F.18. Change in Option Values of 'All' in HRSW Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.7).

Sensitivity Planted Acres For Corn (Combined Acreage of United States and Canada at c=0.7)

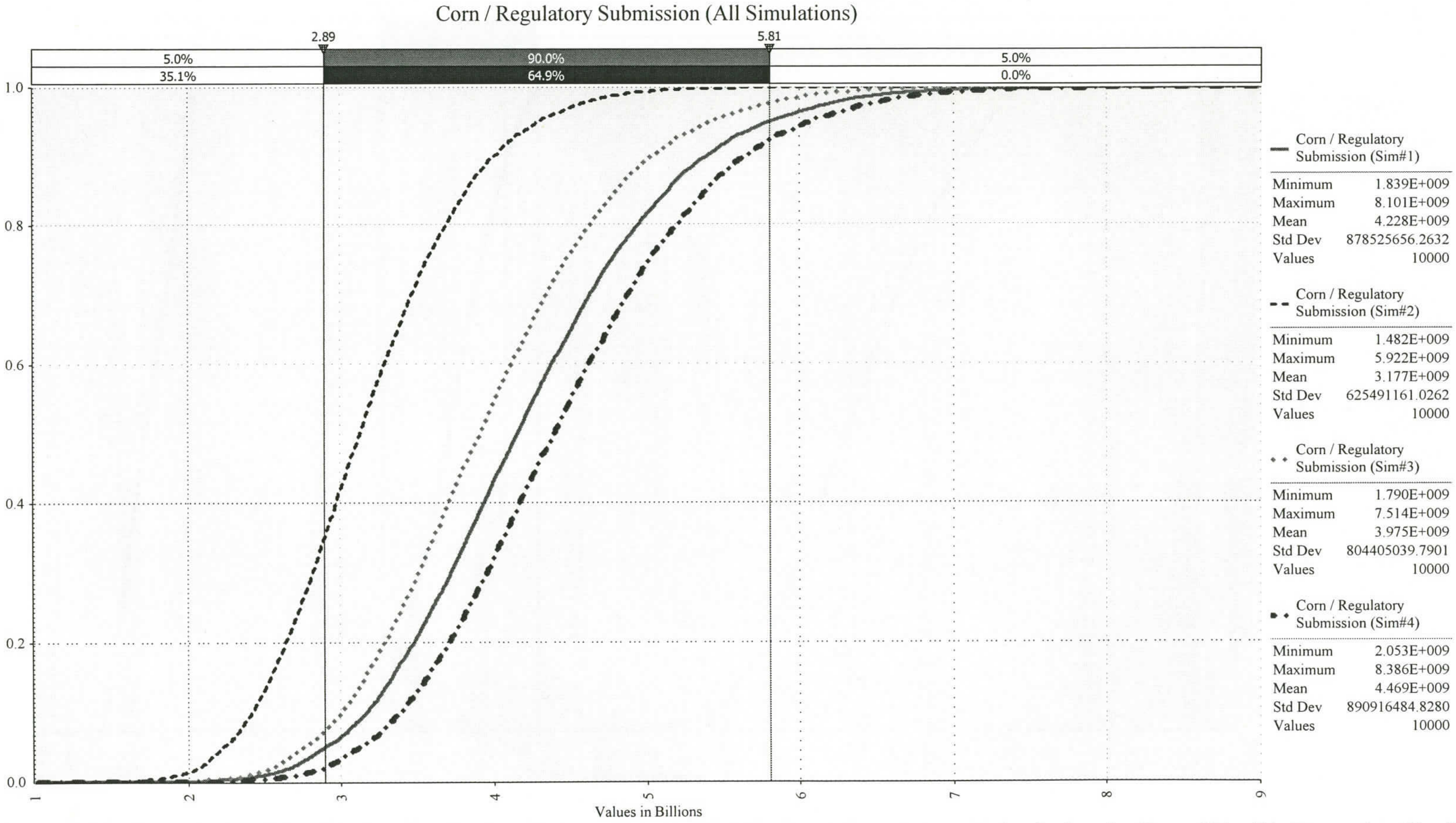


Figure F.19. Cumulative Distribution for Option Values Across GM Traits at Regulatory Submission in Corn (Sim#1=Drought, Sim#2=Cold, Sim#3=NUE,Sim#4='All") for Combined Acreage in United States and Canada($ in millions, c=.7).

Sensitivity Planted Acres For HRSW (Combined Acreage of United States and Canada at c=0.7)

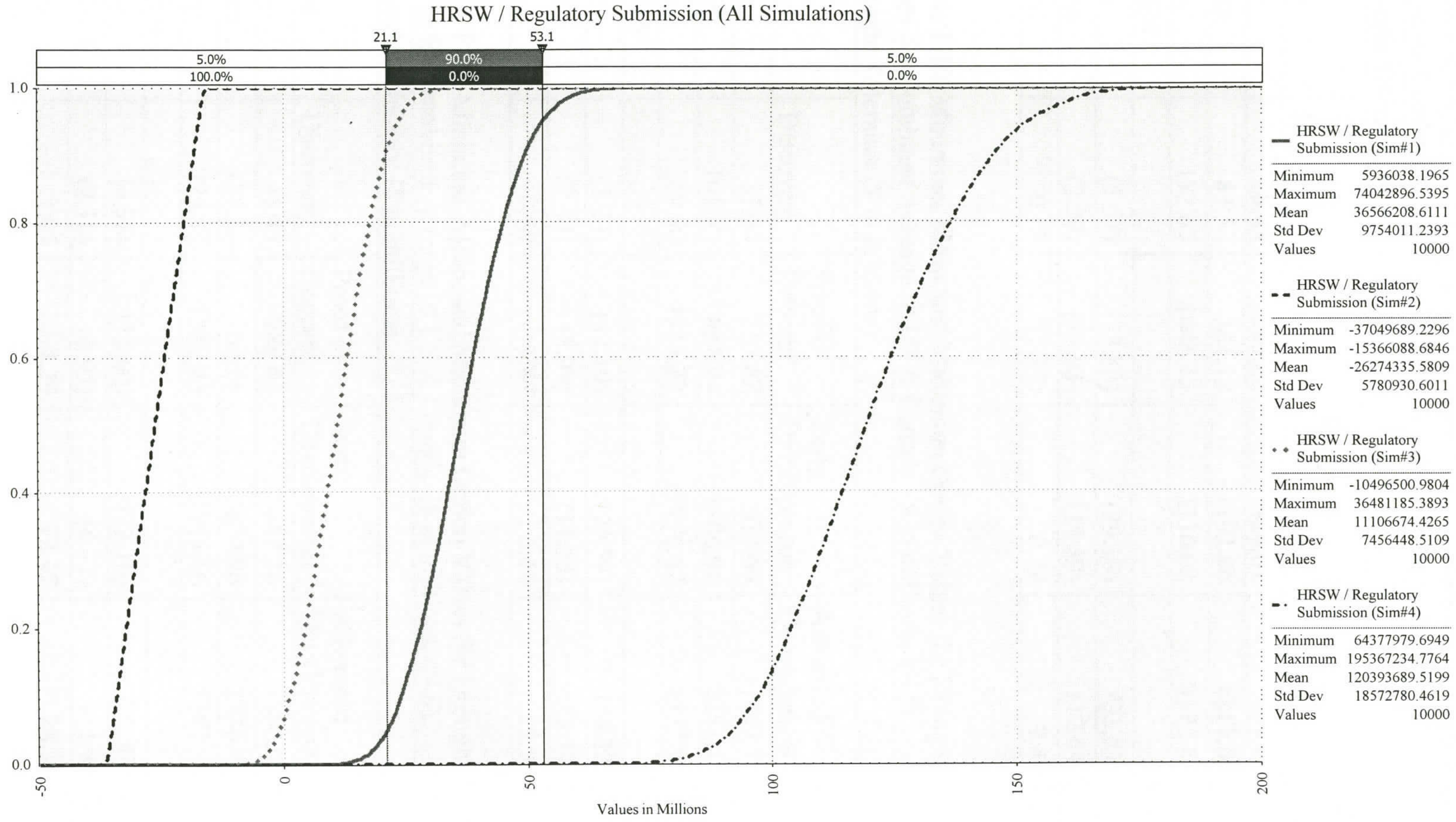


Figure F.20. Cumulative Distribution for Option Values Across GM Traits at Regulatory Submission in HRSW (Sim#1=Drought, Sim#2=Cold, Sim#3=NUE, Sim#4='All") for Combined Acreage in United States and Canada ($ in millions, c=.7).

Sensitivity for Drought Tolerance at Various Shares of Technology Fees

Table F.9. Minimum, Mean, and Maximum Option Values for Drought Tolerance in Crops for Combined Acreage of US & Canada. ($ in millions, c=.4).

Drought Tolerance ($ in millions)					
Corn	Discovery	Proof of Concept	Early Development	Advanced Development	Regulatory Submission
Min	28.85	185.82	420.01	709.09	977.56
Mean	83.53	501.72	1102.86	1817.07	2402.78
Max	182.65	1046.12	2230.08	3572.87	4705.93
HRSW					
Min	(5.57)	(18.80)	(29.18)	(33.81)	(11.56)
Mean	(2.79)	(11.03)	(15.59)	(12.64)	8.03
Max	0.13	(1.35)	0.79	9.49	31.43

Table F.10. Minimum, Mean, and Maximum Option Values for Drought Tolerance in Crops for Combined Acreage of US & Canada. ($ in millions, c=.5).

Drought Tolerance ($ in millions)					
Corn	Discovery	Proof of Concept	Early Development	Advanced Development	Regulatory Submission
Min	37.14	237.82	533.69	897.75	1228.27
Mean	105.45	631.94	1386.91	2281.77	3010.97
Max	229.80	1313.22	2796.62	4477.90	5891.28
HRSW					
Min	(5.23)	(17.10)	(25.59)	(28.33)	(4.52)
Mean	(2.44)	(8.99)	(11.15)	(5.37)	17.54
Max	0.59	1.47	6.47	18.95	44.33

Table F.11. Minimum, Mean, and Maximum Option Values for Drought Tolerance in Crops for Combined Acreage of US & Canada. ($ in millions, c=.6).

Drought Tolerance ($ in millions)					
Corn	Discovery	Proof of Concept	Early Development	Advanced Development	Regulatory Submission
Min	45.43	289.81	647.36	1086.40	1478.98
Mean	127.37	762.16	1670.96	2746.46	3619.17
Max	276.95	1580.33	3363.16	5382.92	7076.63
HRSW					
Min	(4.98)	(15.60)	(22.10)	(22.85)	2.52
Mean	(2.10)	(6.95)	(6.71)	1.89	27.05
Max	1.05	4.29	12.47	28.63	57.23

Table F.12. Minimum, Mean, and Maximum Option Values for Drought Tolerance in Crops for Combined Acreage of US & Canada. ($ in millions, c=.7).

Drought Tolerance ($ in millions)					
Corn	Discovery	Proof of Concept	Early Development	Advanced Development	Regulatory Submission
Min	53.72	341.81	761.04	1275.06	1729.70
Mean	149.30	892.39	1955.01	3211.15	4227.36
Max	324.09	1847.44	3929.70	6287.95	8261.99
HRSW					
Min	(4.74)	(14.12)	(18.80)	(17.47)	9.24
Mean	(1.76)	(4.92)	(2.27)	9.16	36.56
Max	1.51	7.11	18.52	38.30	70.12

Sensitivity Technology Fees for Drought Tolerance: Corn

(Share of Technology Fee as 40, 50, 60, and 70% for Combined Acreage of United States and Canada)

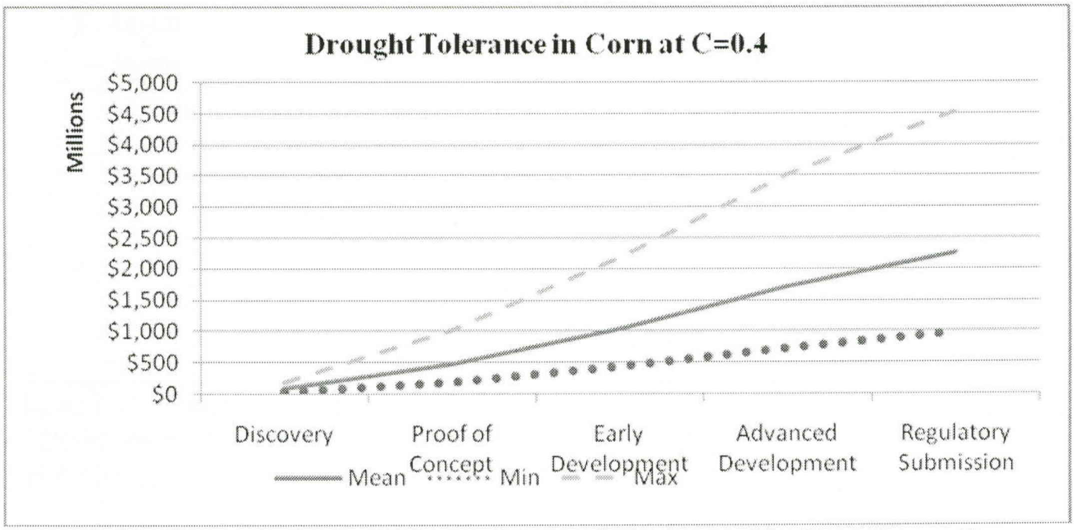


Figure F.21. Change in Option Values of 'Drought Tolerance' in Corn Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.4).

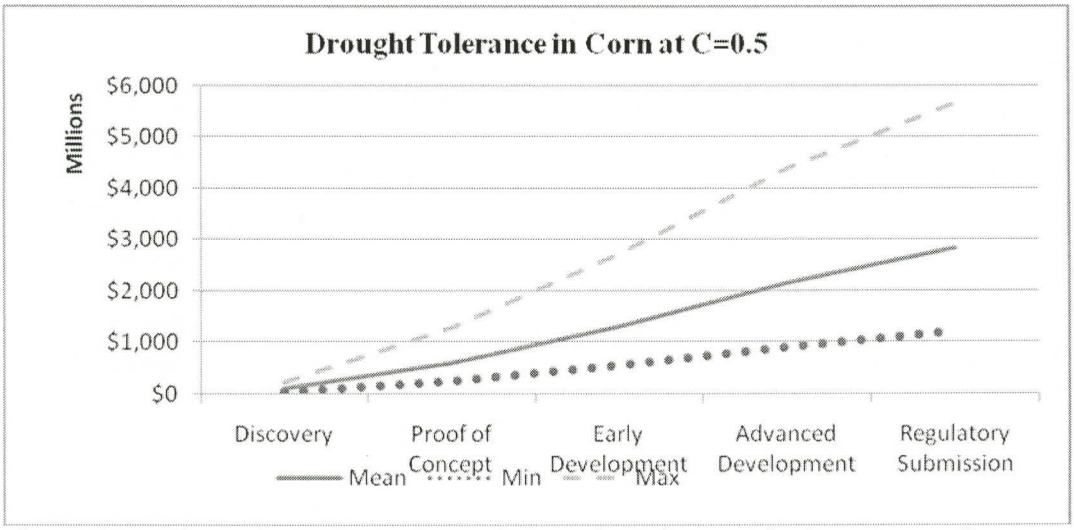


Figure F.22. Change in Option Values of 'Drought Tolerance' in Corn Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.5).

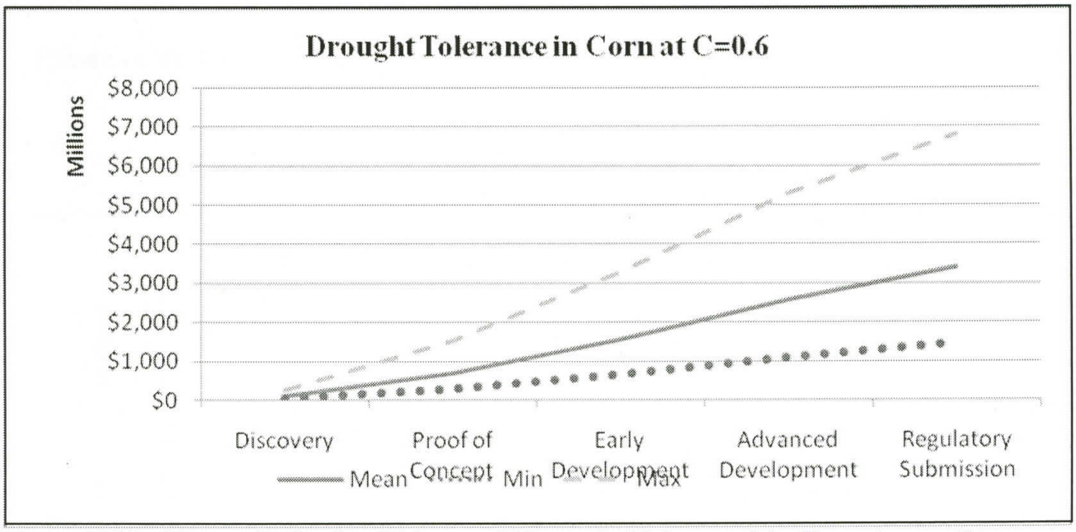


Figure F.23. Change in Option Values of 'Drought Tolerance' in Corn Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.6).

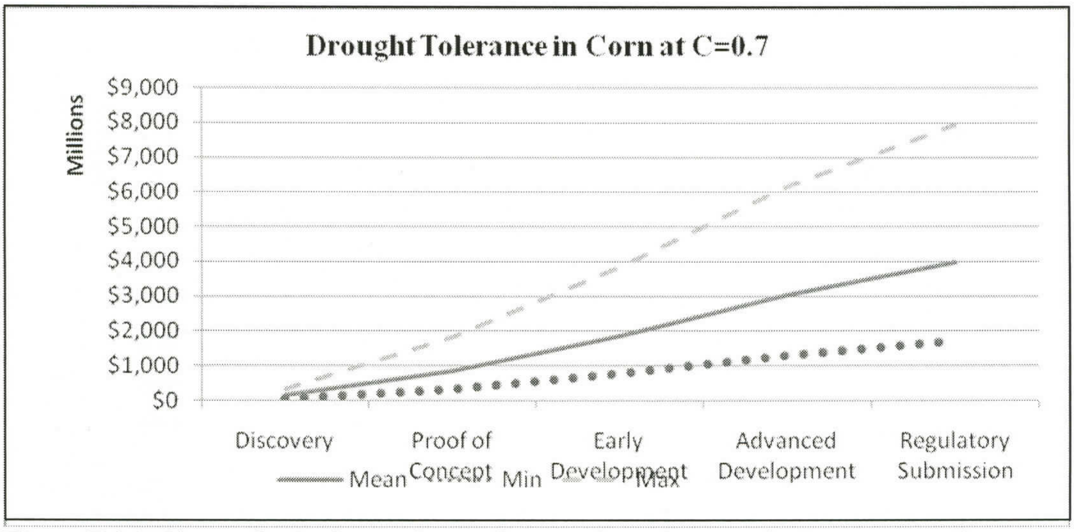


Figure F.24. Change in Option Values of 'Drought Tolerance' in Corn Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.7).

Sensitivity Technology Fees for Drought Tolerance: HRSW

(Share of Technology Fee as 40, 50, 60, and 70% for Combined Acreage of United States and Canada)

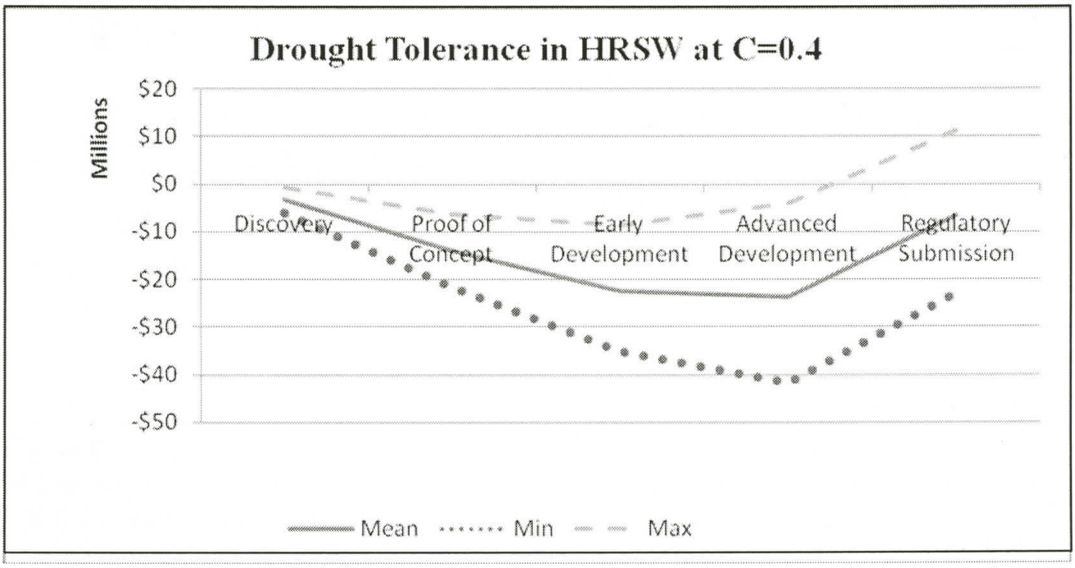


Figure F.25. Change in Option Values of 'Drought Tolerance' in HRSW Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.4).

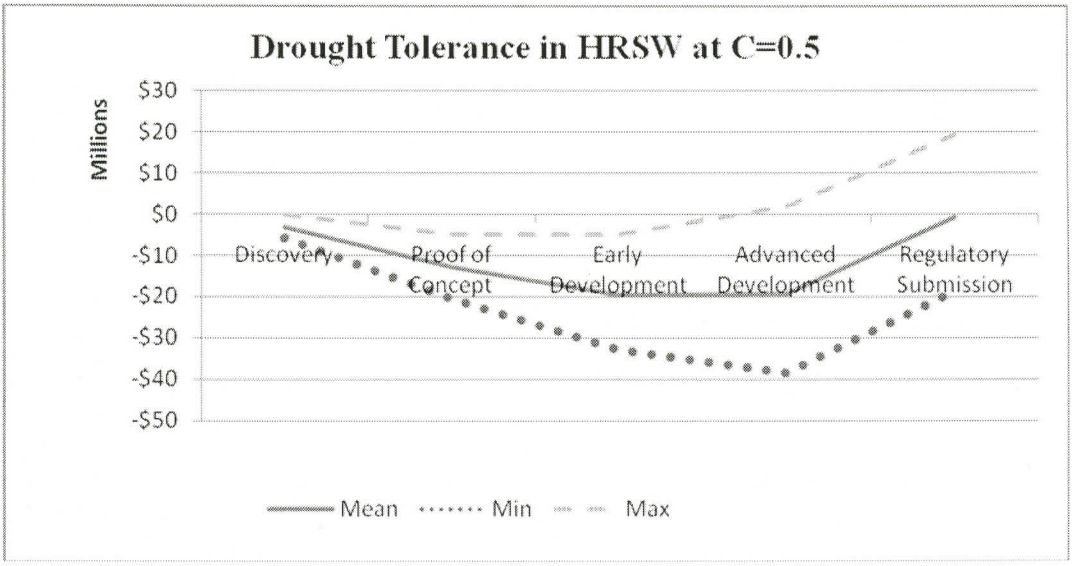


Figure F.26. Change in Option Values of 'Drought Tolerance' in HRSW Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.5).

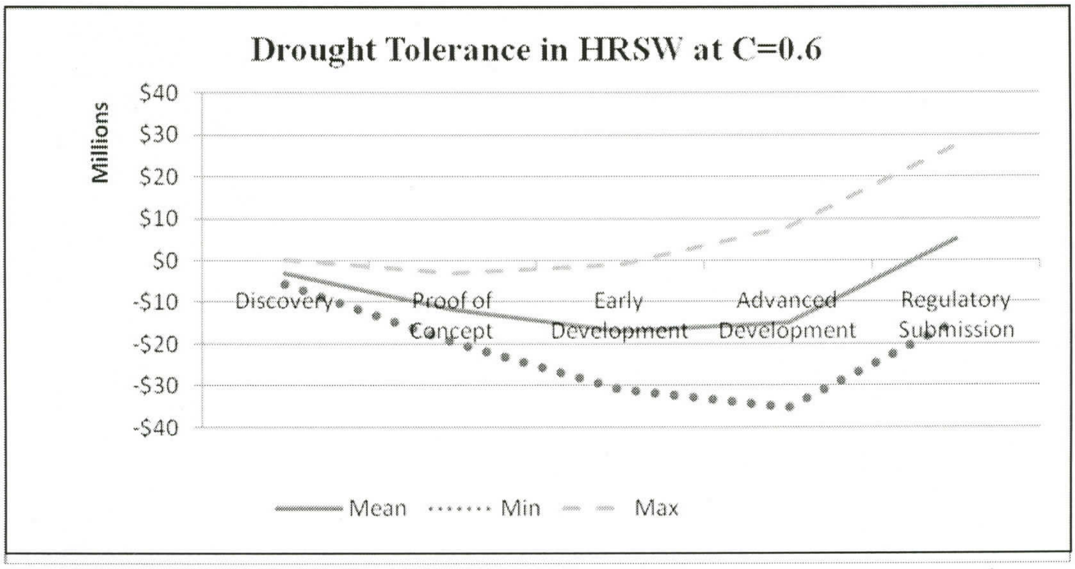


Figure F.27. Change in Option Values of 'Drought Tolerance' in HRSW Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.6).

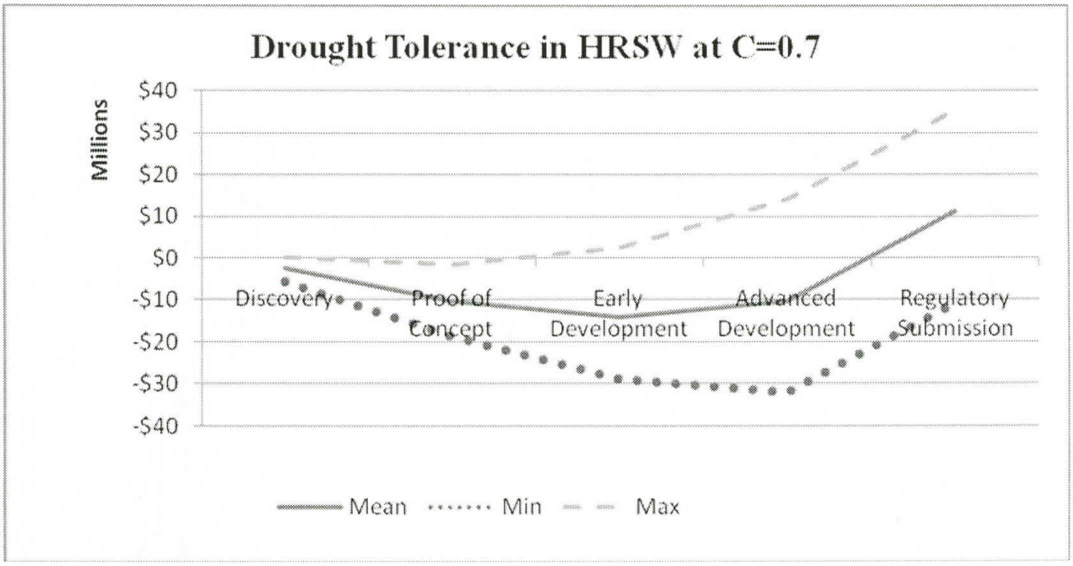


Figure F.28. Change in Option Values of 'Drought Tolerance' in HRSW Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.7).

Sensitivity: Tech. Fees for Drought Tolerance in Corn (Combined Acreage of United States and Canada at c=0.4, 0.5, 0.6, 0.7)

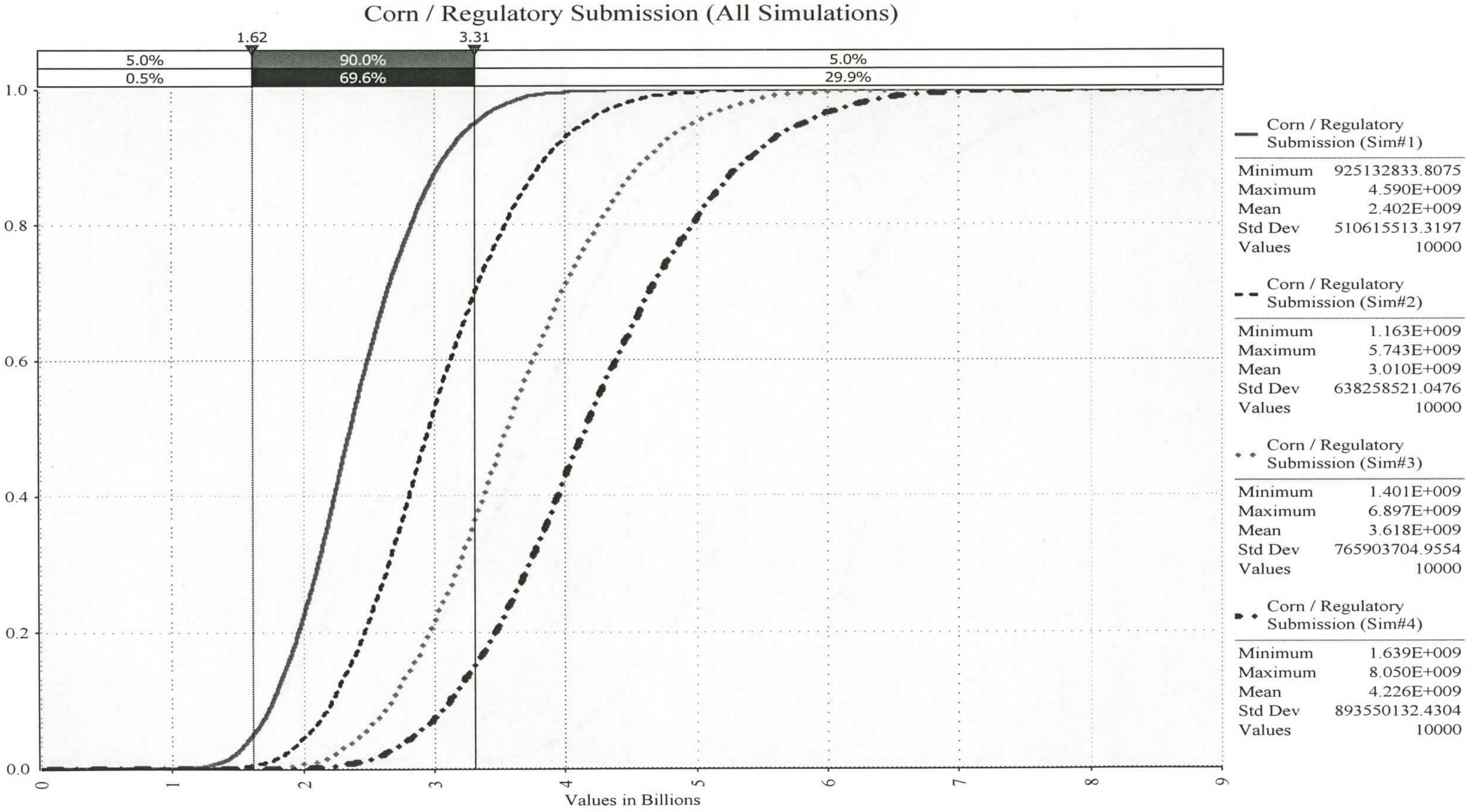


Figure F.29. Cumulative Distribution for Option Values Across GM Traits at Regulatory Submission in Corn (Sim#1=0.4, Sim#2=0.5, Sim#3=0.6, Sim#4=0.7) for Combined Acreage in United States and Canada ($ in millions).

Sensitivity: Tech. Fees for Drought Tolerance in HRSW (Combined Acreage of United States and Canada at c=0.4, 0.5, 0.6, 0.7)

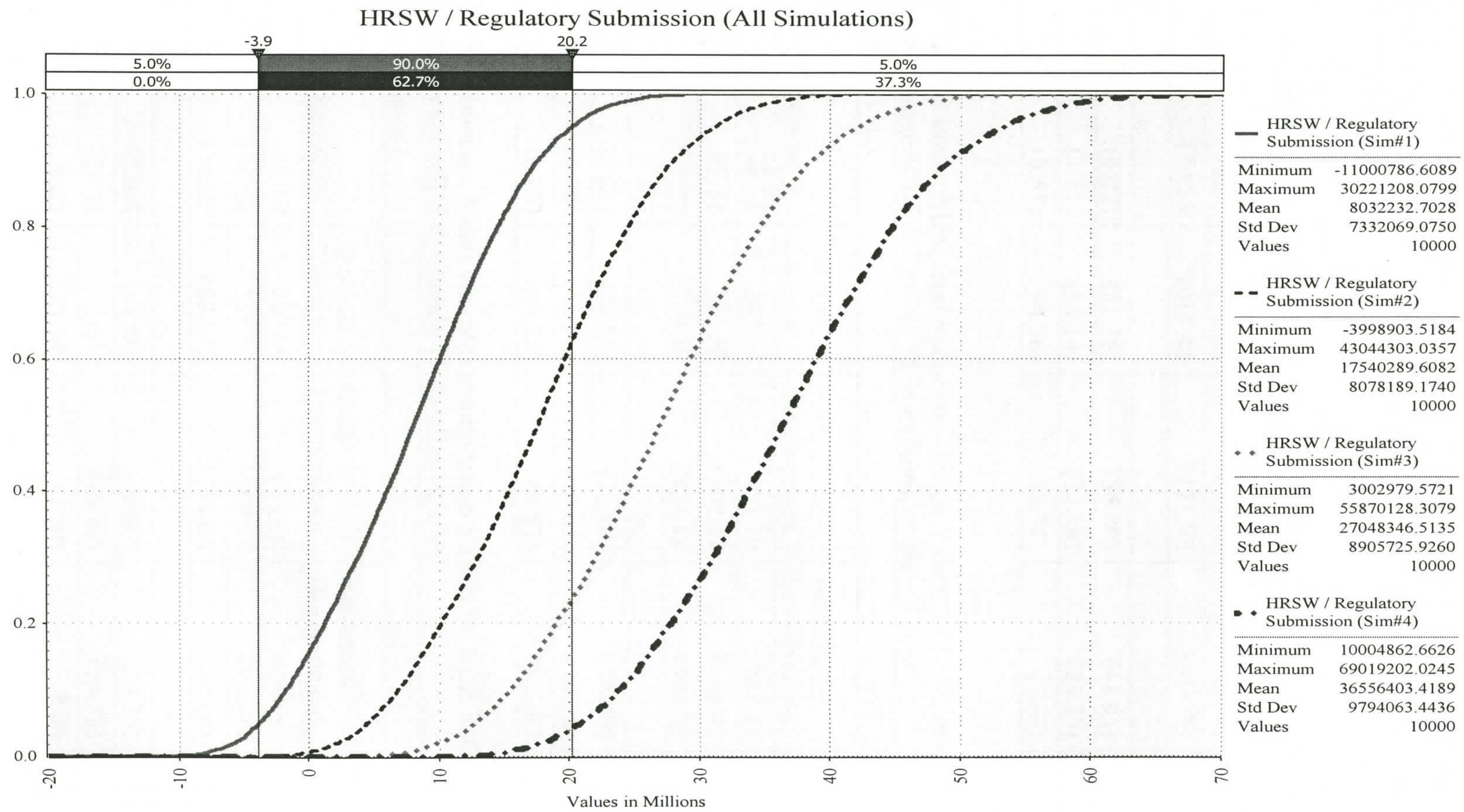


Figure F.30. Cumulative Distribution for Option Values Across GM Traits at Regulatory Submission in HRSW (Sim#1=0.4, Sim#2=0.5, Sim#3=0.6, Sim#4=0.7) for Combined Acreage in United States and Canada ($ in millions).

Sensitivity for NUE at Various Shares of Technology Fees

Table F.13. Minimum, Mean, and Maximum Option Values for NUE in Crops for Combined Acreage of US & Canada. ($ in millions, c=.4).

NUE ($ in millions)					
Corn	Discovery	Proof of Concept	Early Development	Advanced Development	Regulatory Submission
Min	29.99	192.62	438.30	715.62	969.74
Mean	78.30	470.63	1035.10	1706.40	2257.96
Max	179.25	1019.45	2171.92	3511.33	4521.04
HRSW					
Min	(6.02)	(21.76)	(35.20)	(41.95)	(23.05)
Mean	(3.31)	(14.14)	(22.38)	(23.75)	(6.51)
Max	(0.55)	(6.36)	(8.54)	(3.86)	11.37

Table F.14. Minimum, Mean, and Maximum Option Values for NUE in Crops for Combined Acreage of US & Canada. ($ in millions, c=.5).

NUE ($ in millions)					
Corn	Discovery	Proof of Concept	Early Development	Advanced Development	Regulatory Submission
Min	38.55	245.14	555.29	907.15	1220.86
Mean	98.91	593.08	1302.21	2143.42	2829.95
Max	225.26	1279.29	2723.48	4400.88	5660.06
HRSW					
Min	(5.84)	(20.68)	(32.96)	(38.49)	(18.91)
Mean	(3.10)	(12.88)	(19.64)	(19.26)	(0.64)
Max	(0.26)	(4.75)	(4.87)	2.07	19.36

Table F.15. Minimum, Mean, and Maximum Option Values for NUE in Crops for Combined Acreage of US & Canada. ($ in millions, c=.6).

NUE ($ in millions)					
Corn	Discovery	Proof of Concept	Early Development	Advanced Development	Regulatory Submission
Min	47.10	297.66	671.60	1098.67	1471.98
Mean	119.52	715.53	1569.33	2580.44	3401.94
Max	271.27	1539.12	3275.04	5290.43	6799.07
HRSW					
Min	(5.66)	(19.60)	(30.85)	(35.25)	(14.78)
Mean	(2.89)	(11.63)	(16.90)	(14.78)	5.23
Max	0.03	(3.14)	(1.20)	8.00	27.34

Table F.16. Minimum, Mean, and Maximum Option Values for NUE in Crops for Combined Acreage of US & Canada. ($ in millions, c=.7).

NUE ($ in millions)					
Corn	Discovery	Proof of Concept	Early Development	Advanced Development	Regulatory Submission
Min	55.65	350.18	787.91	1290.20	1723.10
Mean	140.14	837.98	1836.44	3017.47	3973.93
Max	317.29	1798.96	3826.61	6179.98	7938.09
HRSW					
Min	(5.48)	(18.53)	(28.74)	(32.02)	(10.65)
Mean	(2.68)	(10.37)	(14.16)	(10.29)	11.11
Max	0.32	(1.53)	2.46	14.04	35.33

Sensitivity Technology Fees for NUE: Corn

(Share of Technology Fee as 40, 50, 60, and 70 % for Combined Acreage of United States and Canada)

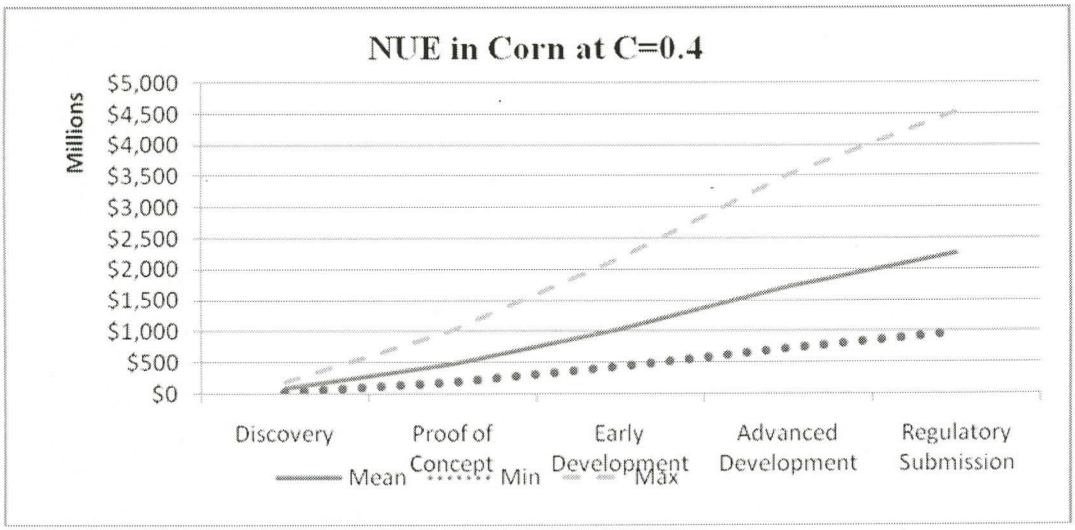


Figure F.31. Change in Option Values of 'NUE' in Corn Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.4).

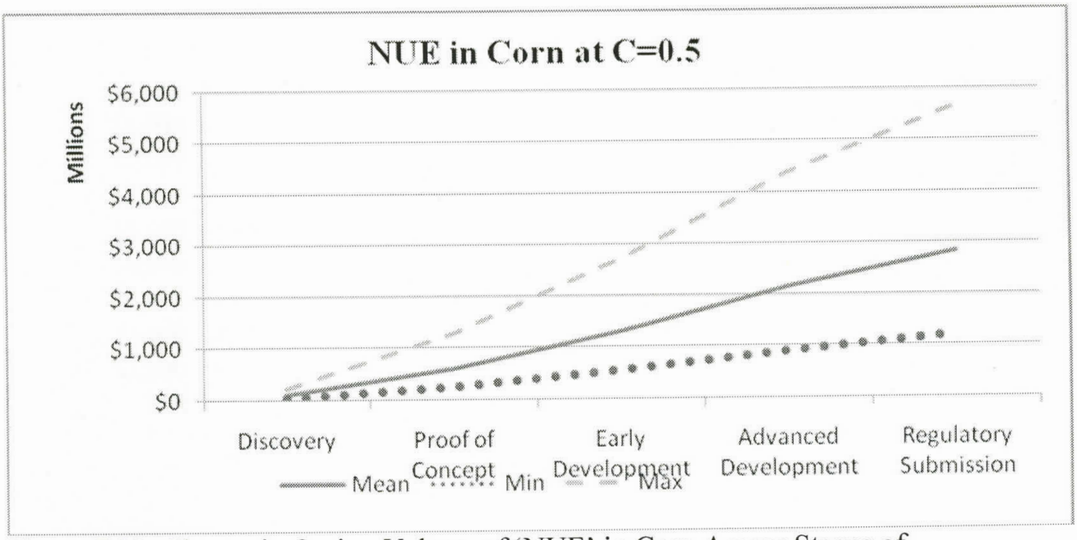


Figure F.32. Change in Option Values of 'NUE' in Corn Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.5).

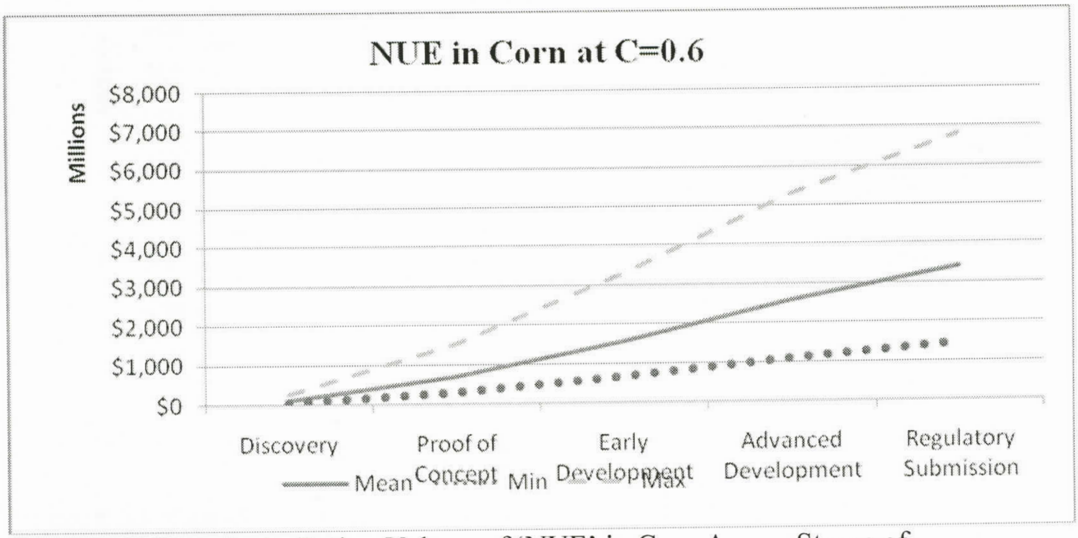


Figure F.33. Change in Option Values of 'NUE' in Corn Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.6).

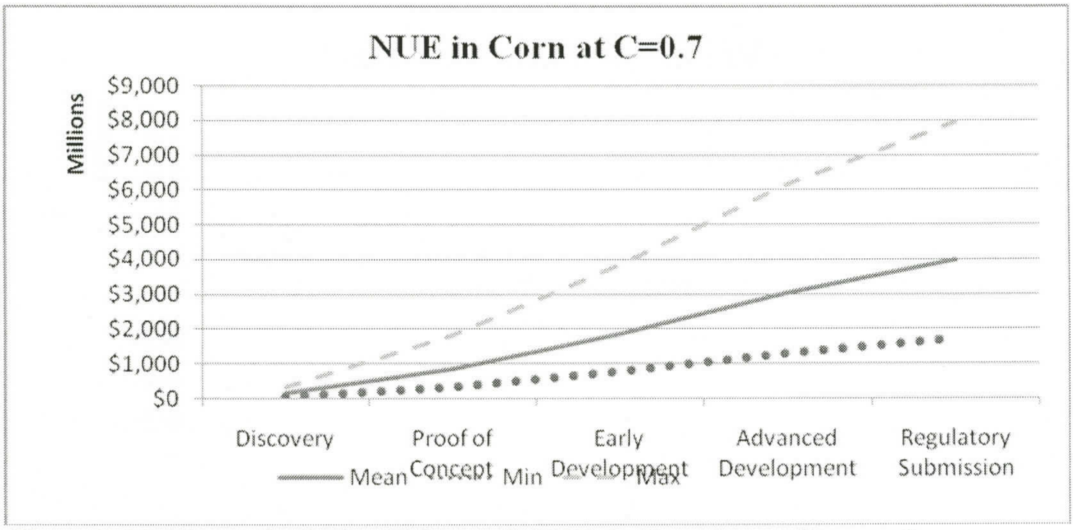


Figure F.34. Change in Option Values of 'NUE' in Corn Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.7).

Sensitivity Technology Fees for Drought Tolerance: HRSW

(Share of Technology Fee as 40, 50, 60, and 70 % for Combined Acreage of United States and Canada)

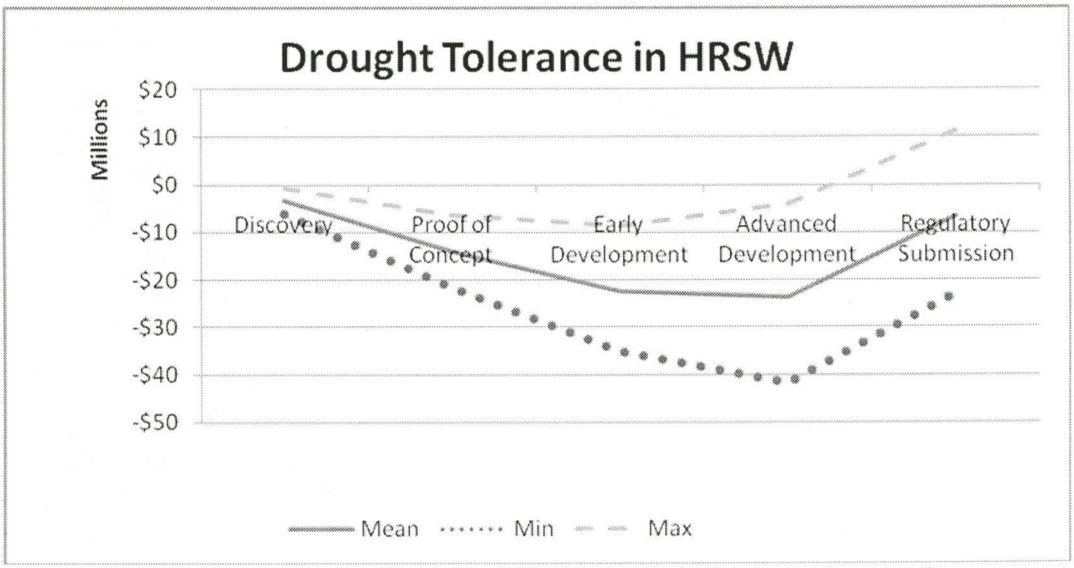


Figure F.35. Change in Option Values of 'NUE' in HRSW Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.4).

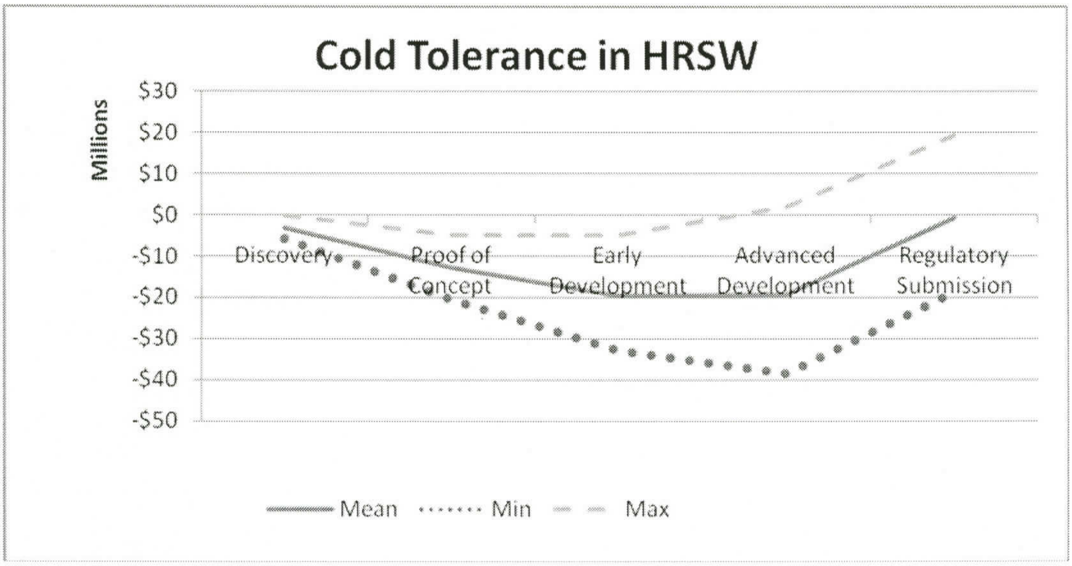


Figure F.36. Change in Option Values of 'NUE' in HRSW Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.5).

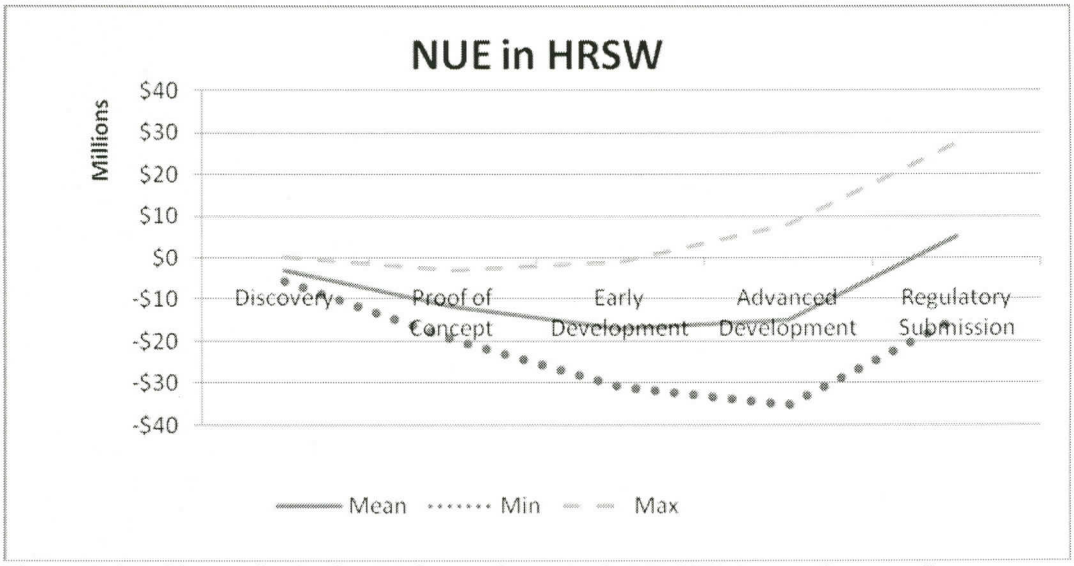


Figure F.37. Change in Option Values of 'NUE' in HRSW Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.6).

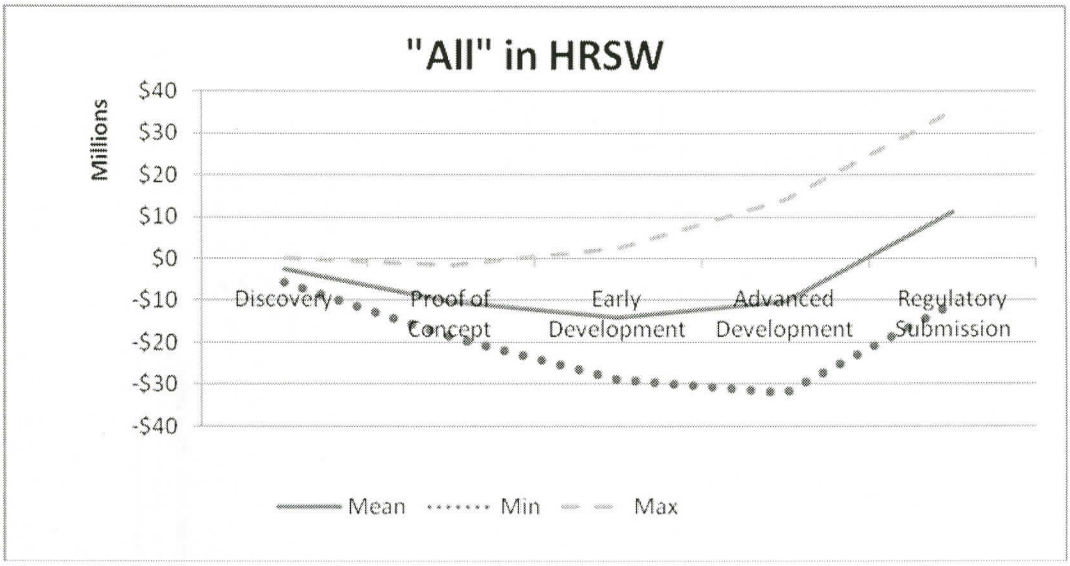


Figure F.38. Change in Option Values of 'NUE' in HRSW Across Stages of Development Showing Minimum, Mean, and Maximum for Combined Acreage of US & Canada. ($ in millions, c=.7).

Sensitivity: Tech. Fees for NUE in Corn (Combined Acreage of United States and Canada at c=0.4, 0.5, 0.6, 0.7)

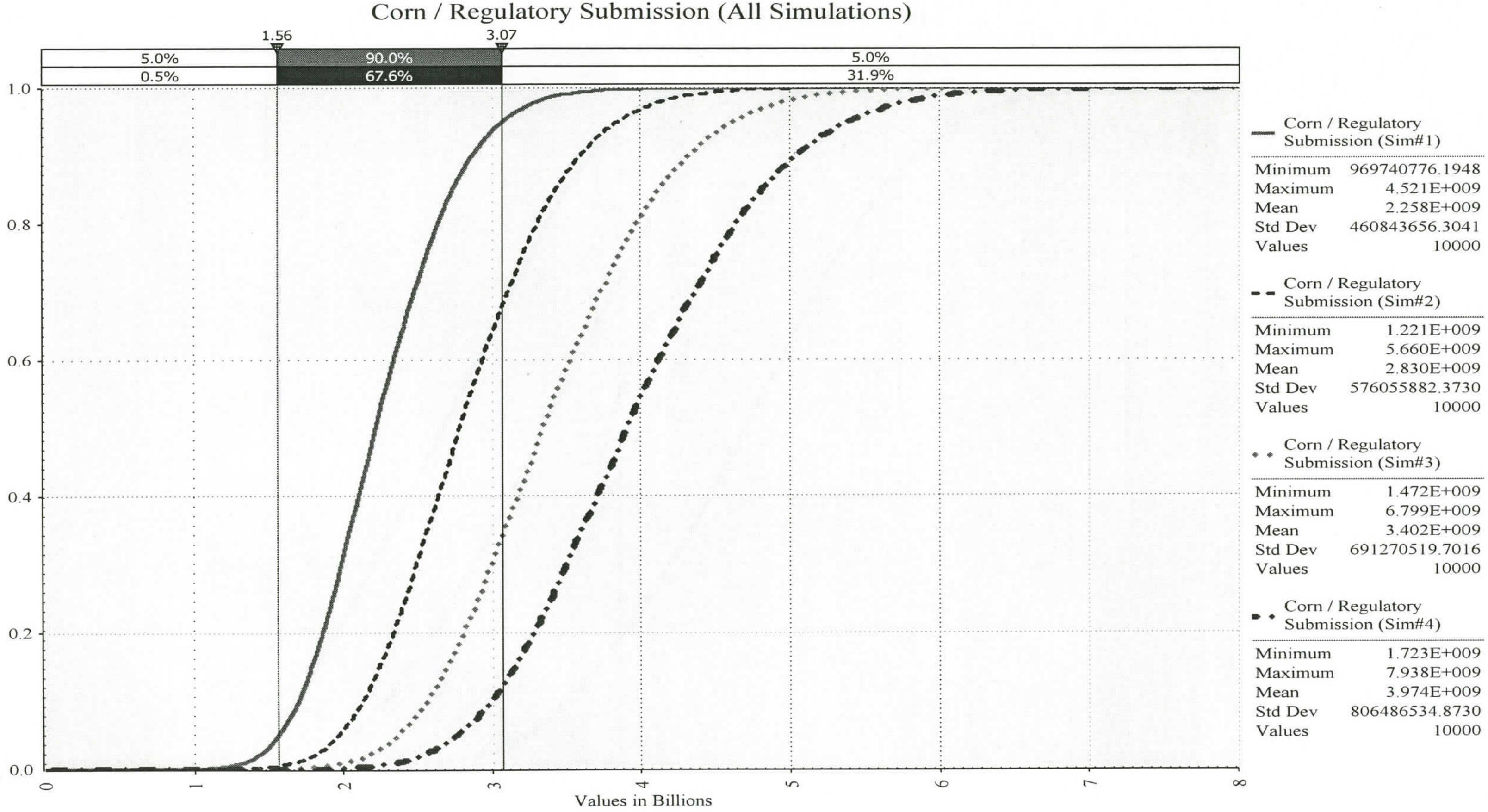


Figure F.39. Cumulative Distribution for Option Values Across GM Traits at Regulatory Submission in Corn (Sim#1=0.4, Sim#2=0.5, Sim#3=0.6, Sim#4=0.7) for Combined Acreage in United States and Canada($ in millions).

Sensitivity: Tech. Fees for Drought Tolerance in HRSW (Combined Acreage of United States and Canada at c=0.4, 0.5, 0.6, 0.7)

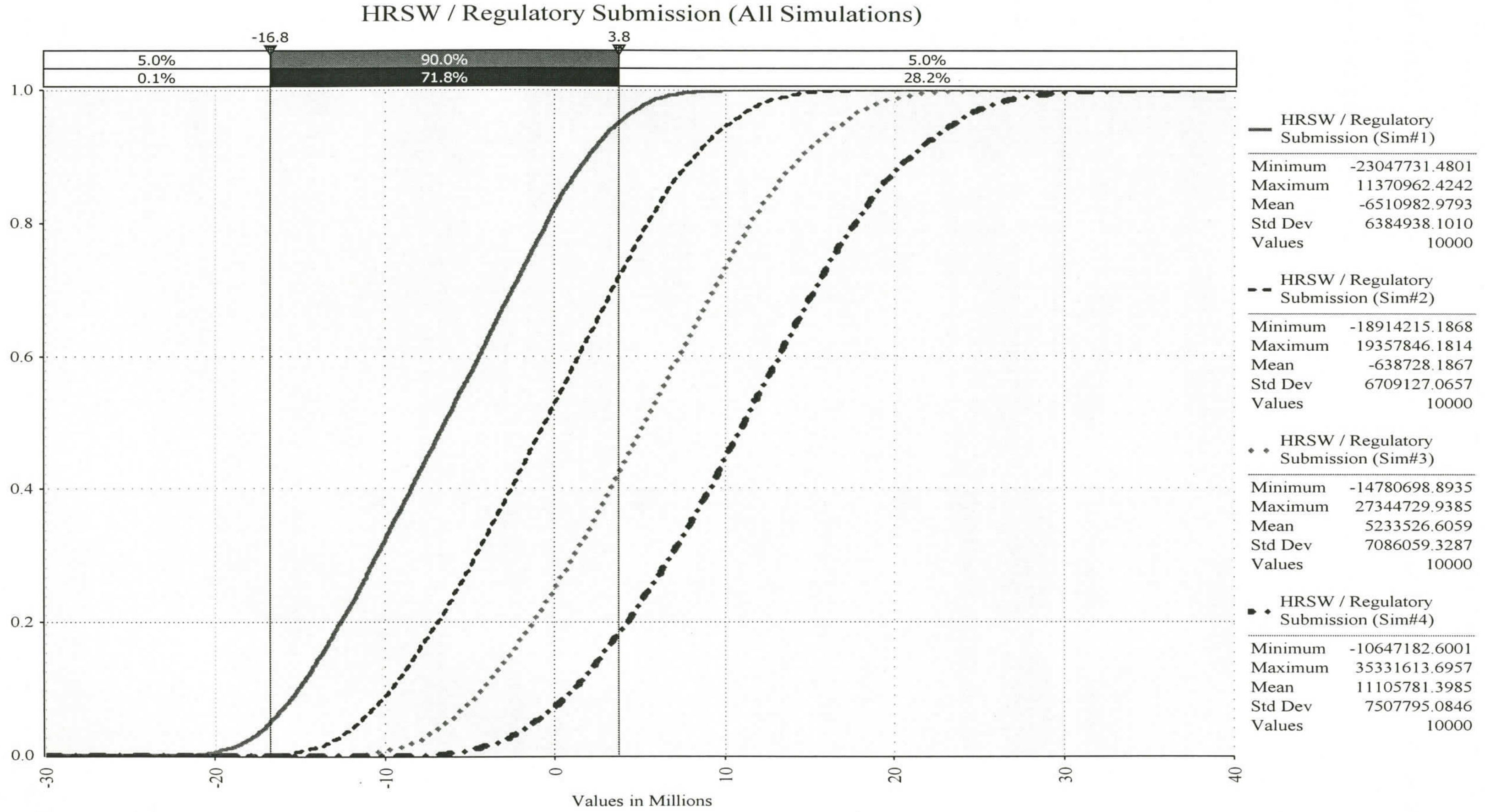


Figure F.40 Cumulative Distribution for Option Values Across GM Traits at Regulatory Submission in HRSW (Sim#1=0.4, Sim#2=0.5, Sim#3=0.6, Sim#4=0.7) for Combined Acreage in United States and Canada($ in millions).

APPENDIX G

This appendix presents results from SERF under negative utility function. Full range of ARAC has been shown for the sake of completeness. Also shown are the weighted risk premiums relative to 1 for corresponding ARACs.

SERF Results HRSW

Table G.1. SERF Under a Neg. Exponential Utility Function (HRSW).

Min RAC	0		1 = Neg. Exponential			
Max RAC	0.15		1			
	ARAC	Base	Drought	Cold	NUE	All
1	0	-7.57	-5.25	-8.06	-5.91	-1.86
2	0.0063	-9.98	-7.54	-10.37	-8.31	-4.16
3	0.0125	-12.23	-9.68	-12.53	-10.54	-6.30
4	0.0188	-14.37	-11.70	-14.57	-12.65	-8.33
5	0.0250	-16.42	-13.66	-16.54	-14.70	-10.29
6	0.0313	-18.43	-15.58	-18.47	-16.70	-12.21
7	0.0375	-20.42	-17.49	-20.39	-18.70	-14.12
8	0.0438	-22.41	-19.42	-22.31	-20.73	-16.05
9	0.0500	-24.43	-21.38	-24.27	-22.82	-18.03
10	0.0563	-26.49	-23.42	-26.29	-25.01	-20.08
11	0.0625	-28.63	-25.56	-28.40	-27.32	-22.24
12	0.0688	-30.85	-27.82	-30.61	-29.79	-24.53
13	0.0750	-33.17	-30.23	-32.95	-32.43	-26.96
14	0.0813	-35.59	-32.80	-35.43	-35.24	-29.54
15	0.0875	-38.11	-35.51	-38.03	-38.21	-32.26
16	0.0938	-40.71	-38.35	-40.74	-41.27	-35.10
17	0.1000	-43.37	-41.28	-43.54	-44.39	-38.01
18	0.1063	-46.05	-44.24	-46.37	-47.50	-40.95
19	0.1125	-48.73	-47.19	-49.21	-50.55	-43.86
20	0.1188	-51.37	-50.08	-52.00	-53.49	-46.71
21	0.1250	-53.95	-52.88	-54.71	-56.31	-49.47
22	0.1313	-56.44	-55.56	-57.32	-58.98	-52.11
23	0.1375	-58.83	-58.11	-59.82	-61.50	-54.62
24	0.1438	-61.12	-60.53	-62.19	-63.87	-57.01
25	0.1500	-63.29	-62.81	-64.43	-66.09	-59.25

Table G.2. Neg. Exponential Utility Weighted Risk Premiums Relative to 1(HRSW).

Base	Base Alternative for Risk Premiums				
ARAC	Base	Drought	Cold	NUE	All
0	-	2.32	(0.49)	1.66	5.71
0.0063	-	2.44	(0.39)	1.67	5.82
0.0125	-	2.56	(0.29)	1.69	5.93
0.0188	-	2.66	(0.20)	1.71	6.04
0.0250	-	2.76	(0.12)	1.73	6.13
0.0313	-	2.85	(0.04)	1.73	6.22
0.0375	-	2.93	0.03	1.71	6.30
0.0438	-	2.99	0.09	1.68	6.36
0.0500	-	3.04	0.15	1.60	6.40
0.0563	-	3.07	0.20	1.48	6.41
0.0625	-	3.07	0.23	1.30	6.39
0.0688	-	3.02	0.23	1.06	6.32
0.0750	-	2.93	0.21	0.73	6.21
0.0813	-	2.79	0.16	0.34	6.05
0.0875	-	2.59	0.08	(0.10)	5.84
0.0938	-	2.35	(0.04)	(0.57)	5.60
0.1000	-	2.09	(0.17)	(1.03)	5.35
0.1063	-	1.81	(0.32)	(1.45)	5.10
0.1125	-	1.54	(0.48)	(1.82)	4.87
0.1188	-	1.29	(0.62)	(2.12)	4.66
0.1250	-	1.07	(0.76)	(2.36)	4.48
0.1313	-	0.88	(0.88)	(2.54)	4.33
0.1375	-	0.72	(0.98)	(2.67)	4.21
0.1438	-	0.59	(1.07)	(2.75)	4.11
0.1500	-	0.48	(1.15)	(2.80)	4.03

SERF Results Corn

Table G.3. SERF Under a Neg. Exponential Utility Function(Corn).

Min RAC	0		1 = Neg. Exponential			
Max RAC	0.15		1			
	ARAC	Base	Drought	Cold	NUE	All
1	0	-28.25	-27.79	-24.08	-25.30	-23.36
2	0.0063	-42.82	-42.68	-38.96	-39.59	-37.67
3	0.0125	-57.97	-55.47	-53.13	-52.98	-50.93
4	0.0188	-83.93	-67.38	-68.33	-66.76	-63.78
5	0.0250	-140.43	-79.37	-87.00	-81.93	-76.78
6	0.0313	-203.95	-92.25	-111.12	-98.93	-90.41
7	0.0375	-251.91	-106.45	-138.60	-117.08	-104.77
8	0.0438	-286.85	-121.54	-164.71	-134.88	-119.41
9	0.0500	-313.14	-136.48	-187.03	-151.13	-133.56
10	0.0563	-333.60	-150.31	-205.46	-165.34	-146.59
11	0.0625	-349.97	-162.62	-220.67	-177.56	-158.20
12	0.0688	-363.37	-173.38	-233.34	-188.03	-168.40
13	0.0750	-374.53	-182.74	-244.01	-197.02	-177.32
14	0.0813	-383.98	-190.89	-253.12	-204.80	-185.13
15	0.0875	-392.07	-198.04	-260.97	-211.57	-192.01
16	0.0938	-399.09	-204.34	-267.81	-217.51	-198.10
17	0.1000	-405.23	-209.92	-273.81	-222.75	-203.51
18	0.1063	-410.65	-214.90	-279.13	-227.41	-208.36
19	0.1125	-415.47	-219.37	-283.87	-231.58	-212.71
20	0.1188	-419.78	-223.41	-288.12	-235.32	-216.66
21	0.1250	-423.65	-227.06	-291.95	-238.70	-220.24
22	0.1313	-427.16	-230.39	-295.42	-241.78	-223.50
23	0.1375	-430.35	-233.43	-298.58	-244.58	-226.49
24	0.1438	-433.26	-236.22	-301.47	-247.14	-229.24
25	0.1500	-435.93	-238.79	-304.13	-249.49	-231.78

Table G.4. Neg. Exponential Utility Weighted Risk Premiums Relative to 1(Corn).

Base Scenario					
Base	Base Alternative for Risk Premiums				
ARAC	Base	Drought	Cold	NUE	All
0	-	0.46	4.17	2.94	4.88
0.0063	-	0.14	3.86	3.23	5.14
0.0125	-	2.49	4.83	4.98	7.03
0.0188	-	16.54	15.59	17.17	20.15
0.0250	-	61.06	53.43	58.50	63.65
0.0313	-	111.70	92.83	105.01	113.54
0.0375	-	145.46	113.31	134.83	147.15
0.0438	-	165.30	122.13	151.96	167.44
0.0500	-	176.66	126.11	162.01	179.57
0.0563	-	183.29	128.14	168.26	187.01
0.0625	-	187.35	129.30	172.41	191.77
0.0688	-	189.99	130.03	175.34	194.97
0.0750	-	191.79	130.52	177.51	197.21
0.0813	-	193.08	130.86	179.18	198.84
0.0875	-	194.04	131.10	180.50	200.06
0.0938	-	194.76	131.28	181.58	201.00
0.1000	-	195.31	131.42	182.48	201.72
0.1063	-	195.75	131.52	183.24	202.30
0.1125	-	196.09	131.60	183.89	202.75
0.1188	-	196.37	131.66	184.45	203.12
0.1250	-	196.59	131.71	184.95	203.42
0.1313	-	196.77	131.74	185.39	203.66
0.1375	-	196.92	131.77	185.78	203.86
0.1438	-	197.04	131.79	186.13	204.02
0.1500	-	197.14	131.81	186.44	204.16