DEVELOPING A MODEL TO VALUE GERMPLASM USING REAL OPTIONS

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

Marit Simonson-Paschke

In Partial Fulfillment of the Requirements
For the Degree of
MASTERS OF SCIENCE

Major Department:

Agribusiness and Applied Economics

July 2013

Fargo, North Dakota

North Dakota State University
Graduate School

Title

Developing a Model to Value Germplasm Using Real Options

By

Marit Simonson-Paschke

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

SUPERVISORY COMMITTEE:

William Wilson
Chair

Ryan Larsen

Saleem Shaik

Ruilin Tian

Approved:

7/18/2013
Date

William Nganje
Department Chair

ABSTRACT

With many varieties of germplasm being developed, it is imperative to the industry that firms decide on a valuation method. This need to include looking at traits of the germplasm, the risk and uncertainty of expected returns associated with a varieties' development and release.

The purpose of this thesis is to determine the option value of developing germplasm using the real options approach. The value gained of the variety will be measured and used as a decision factor in the determining the value of the germplasm at different development phases. This approach helps managers decide the best possible option in making a certain decision today, or in the future. Two possible options to "continue" or "wait" are modeled in this thesis. Such modeling determines the possible option values of germplasm at different stages of development depending on changes in value and various choices made at different points in time.

ACKNOWLEDGEMENTS

My sincerest thanks go to my adviser, Dr. William W. Wilson, for his expert guidance and comments during the process of completing this thesis. He sets a standard of hard work and success for all his students. In addition, a special thanks go to all of my committee members, Dr. Saleem Shaik, Dr. Ryan Larsen, and Dr. Ruilin Tian, for their time and useful insight. Also, Mr. Bruce Dahl deserves many thanks for taking the time to answer all my questions, no matter how small. His experience proved very valuable in the competition of this thesis.

I would also like to thank my family members. Without their unconditional love, support, and blessing, I would not have been able to accomplish a master's degree. Their unrelenting motivation for education and knowledge helped me stay the course through the most frustrating and toughest of times. Also, I would like to thank my husband, Matthew Lau, for all his support and encouraging words.

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1. INTRODUCTION AND PROBLEM STATEMENT

Introduction

Innovation is a theme in today's society. People are constantly acquiring new knowledge about products and the underlying physical processes used to make these products. One of the most noteworthy innovations in recent times has been the patenting and valuing of plants, animals, and microorganisms. New and improved biotechnology methods such as tissue cell culture, DNA mapping, and genetic engineering have helped make it possible for researchers to reduce the time needed to improve plant varieties along with increasing their precision in modifying plant traits.

The ability to quantify the current and future value of germplasm, along with the risks, given costs, and options, of wheat during different development stages, is important for accountants, buyers of licensing agreements, investors, patent holders, financial managers, and executives. Decisions makers must be able to allocate finite budgets to projects that will maximize the firm's long-term profitability and revenue stream. There are risks of failure as well as the option to continue or stop producing. The accuracy of the validation method is a critical function in operational efficiency and shareholder value. The model developed for this thesis was created to capture risks of the variety development process.

Problem Statement

As the number of genetic traits discovered and the number of patents for germplasm increase, it is becoming more important that firms (biotechnology companies and research universities) determine the value of germplasm. The purpose of this thesis is to determine the option value of developing germplasm using the real-options approach. The real options approach provides a way of modeling uncertain values for an investment in germplasm. Traditional investments are valued by the net-present-value (NPV) or discounted-cash-flow (DCF). The NPV approach looks at a time series of cash flows, both incoming and outgoing, and finds the present value. The DCF framework discounts an asset's expected future cash flows by a predetermined rate. This traditional framework, however, ignores the values of options and risks associated with contingent decision making. To account for this value and the opportunities created by uncertainty, the real-options method is used.

Elements of the Problem

There are two primary problems associated with valuing germplasm. First, the expected cash flow from the commercialization of germplasm characteristics is uncertain. The decision maker must be able to accurately forecast the germplasm value based on domestic and international adoption rates, along with improvement of the germplasm itself. Additionally, the structure of the wheat breeding industry affects uncertainty with competing products and the technology charge for genetically modified seed. Product demand and price need to be considered to develop an accurate valuation framework.

The second problem is the cost of developing the germplasm. There are specific risks and costs attributed to each phase in the development process. A useable model must take all of these uncertainties into account.

Wheat Breeding

Wheat breeding can be broken into several stages, from F1-F8, after which are the advanced lines and yield trait stages. Traditional wheat breeding methods require up to 12 years of research to successfully produce a new wheat variety. At North Dakota State University (NDSU) germplasm from many wheat-breeding programs, including United State Department of Agriculture, International Maize and Wheat Improvement Center (CIMMYT), and others, are evaluated on an ongoing basis for desirable agronomic, pest resistance, and quality characteristics. The selected genotypes are used as parents to cross with North Dakota adapted spring wheat germplasm for sexual recombination to develop new breeding populations. Crosses are made in the greenhouse. Several generations of backcrossing may be necessary if the newly introduced parent is not adapting correctly or if there is a need to improve one of the parents for a qualitative trait such as stem rust resistance. To improve the population, recurrent selection may be used on a limited basis to increase the gene frequency of a desired population trait or to combine certain desired traits. Marker Assisted Selections (MAS) and the double haploid technique are used to screen the germplasm for genes of interest. The alternative would be to screen using the germplasm's phenotype, but this process is more time consuming.

Breeding populations are evaluated in the early generations (F2-F4) and then selected based on agronomic and disease traits and for grain protein in the F4 generation. This process is done at the NDSU research stations in Casselton and Prosper, ND. F3 lines are tested in the greenhouse for stem rust resistance by seedling inoculation with a composite of different stem rust races. MAS is used when appropriate. Evaluation in the early generations is done by project personnel. Preliminary yield trials of the F5, F3 derived and F6, F4 derived lines are conducted at the Casselton and Prosper sites as well as at the North Central Research Extension Center. Depending on the seed quality available for testing the experimental lines, the number of replicates for each trail varies. Seed comes from the previous year's head rows at North Dakota nurseries. The advanced yield trials of the F6 and F7 lines are conducted at the same three sites along with the Carrington Research Extension Center. These breeding lines are evaluated for agronomic and disease traits. All new lines need to be tested for stem-rust resistance in the campus greenhouse.

Cost of Germplasm Development

A major area of agricultural research is plant breeding, or the improvement of crop plants through genetic manipulation and selection. The costs of wheat breeding can be broken into the cost of: (a) the breeder's activities; (b) disease evaluation, (c) quality testing, (d) comparative evaluations with excising cultivars (information costs), (e) information regarding agronomic requirements, (f) any release or registration procedures, (g) extension over and the ethos required for existing cultivars, and (h) costs for growers or additional inputs (e.g., higher harvesting costs for higher-yielding cultivar) required over and above those required for other cultivars (Brennan, 1989).

An overview schedule of a wheat breading program is shown in Figure 1.1. The overall aims and objectives of a breeding program are determined by economic information and data on the target growth region. A particular cross can be modified by the current cultivars and the resources available to breeders. Parent plants are selected and then, a breeding approach is determined. Selection can take place after a variable population is generated. When a superior line emerges, it leads to the release of a new cultivar. There are costs that occur at each stage of the breeding and selection process.

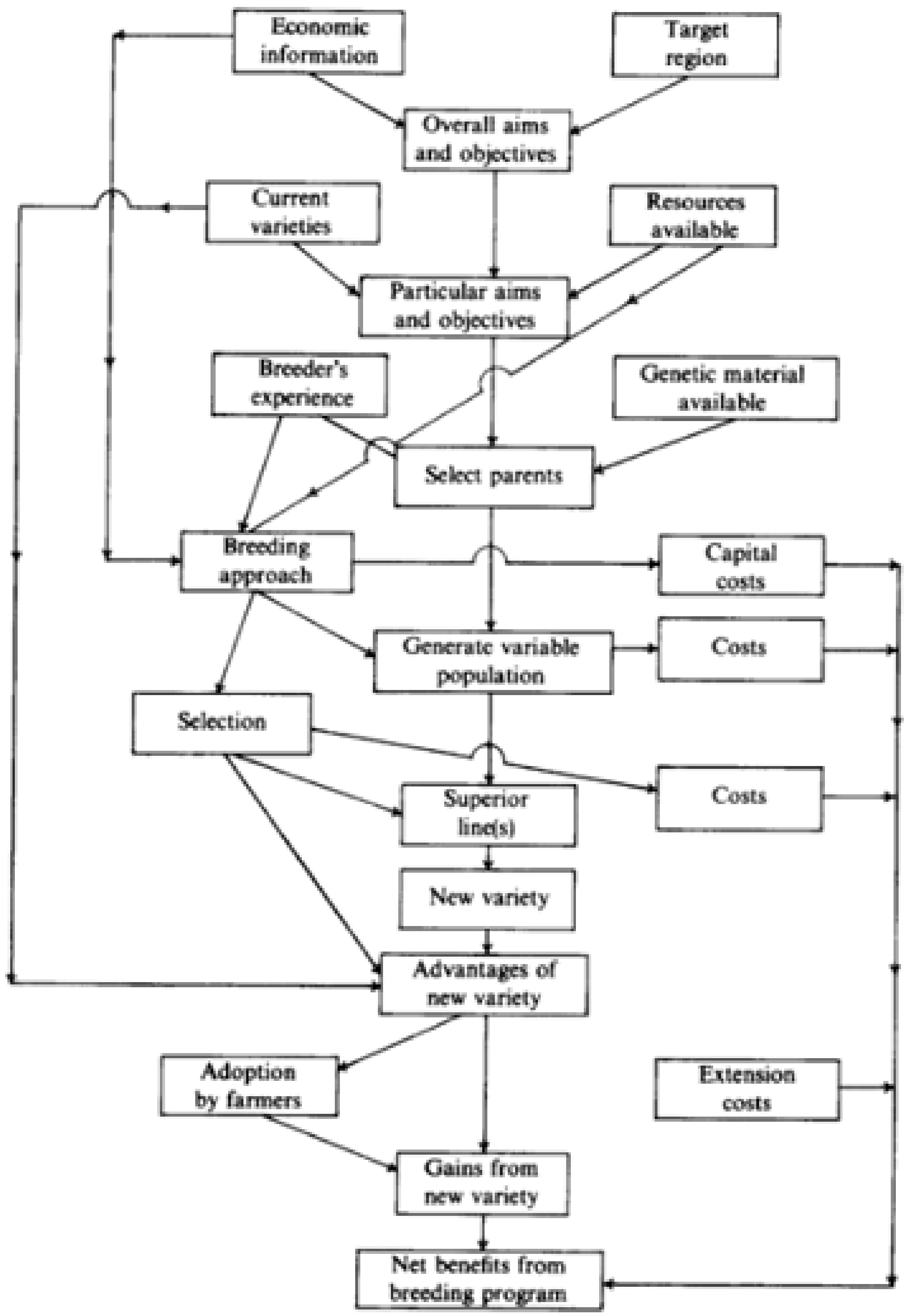

Figure 1.1. Breeding Program (Brennan, 1989)

Valuing Germplasm

Historically, genetic resources have been used as public goods and are uncounted in agricultural research production budgets. Primary gene pools and agro-ecosystems at centers of crop origins contain different components and levels of genetic and cultural information: individual genes and their variants, genotypes, crop populations, wild and weedy crop relatives, farmer knowledge, and seed networks among farmers (Brush, 1996). One of the more difficult aspects of pricing genetic resources is addressing all the different components in a single framework.

Two different approaches are available for use in valuing biological resources: market and nonmarket. Privatization of resources through property rights and the use of contracts are utilized in the market method. Nonmarket methods use an indirect value assessment of value because biological resources are not sold in a market. This method is used in relation to clean air or a wildlife population. In the cased of this thesis, property rights are used.

The two general market mechanisms that exist for valuing genetic resources are intellectual property and contracts for exploration and extraction. Intellectual property was not considered to be a viable option in the past because most crop genetic resources were part of the public domain. This situation is becoming less of the case as more innovations are patented or privatized. Contracts, on the other hand, are a way to avoid problems associated with intellectual property, such as the monopolization of goods or innovations.

Hypothesis

It is expected that the real-options approach to value the agbiotechnology development-cycle yields will increase project valuations. This increase is expected because the real-options framework gives management flexibility and recognizes the contingent nature of the development process.

Through the process of this thesis, the real-options methodology is applied to the F1-F11 stages of breeding for Hard Red Spring Wheat to determine the value of the germplasm. The model evaluates the costs, risks, and options to help determine the best decision. This thesis differs from previous literature because, although real options have been applied to agbiotechnology, they have not been specifically applied to germplasm. Additionally, this methodology can then be used as a way to evaluate germplasm research and development budgets at NDSU.

Organization of Thesis

Chapter 2 thoroughly describes intellectual property rights and the real options method. A review of previous literature relating to the problems addressed in this thesis is provided. Chapter 3 provides a theoretical description for the foundation of real-options model building. Chapter 4 provides an empirical model for evaluating germplasm using the real options framework. Chapter 5 consists of a valuation analysis of germplasm using the model developed in Chapter 4. Chapter 6 ends this thesis with conclusions, implications, and limitations.

Methodology

The methodology includes the validation of analyzing germplasm at different phases of development using real options. Wheat-breeding costs and the probability of proceeding to the next stage, along with profits, are used in the model. Other inputs include the risk free rate, adoption rates, and increased values of protein and yield.

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

2. BACKGROUND AND REVIEW OF LITERATURE

Background

The increased private activity in germplasm has led to research in several areas. There has been substantial work done in the area of intellectual property rights. In addition, numerous studies have analyzed the value of a plant's genetic resources. The following section presents previous work about the importance of the valuation of the agbiotechnology development process. This chapter is organized in five main sections: (1) economics of breeding, (2) description of wheat breeding activities, (3) the valuing of plant genetic resources and intellectual property rights, (4) previous studies using real options as the valuation methodology, and (5) previous literature about real-option applications, specifically those related to biotechnology and agriculture.

Agriculture Biotechnology Industry Structure

Historically, agriculture research and development were almost entirely done at public institutions and land grant universities. This industry, however, has begun to change because of advances in biotechnology, expanded intellectual property rights for biological inventions, and the globalization of agricultural input markets(Klotz-Ingram & Day-Rubenstien, 1999). All these factors have contributed to the increased involvement of the private sector in agricultural research and development (R&D).

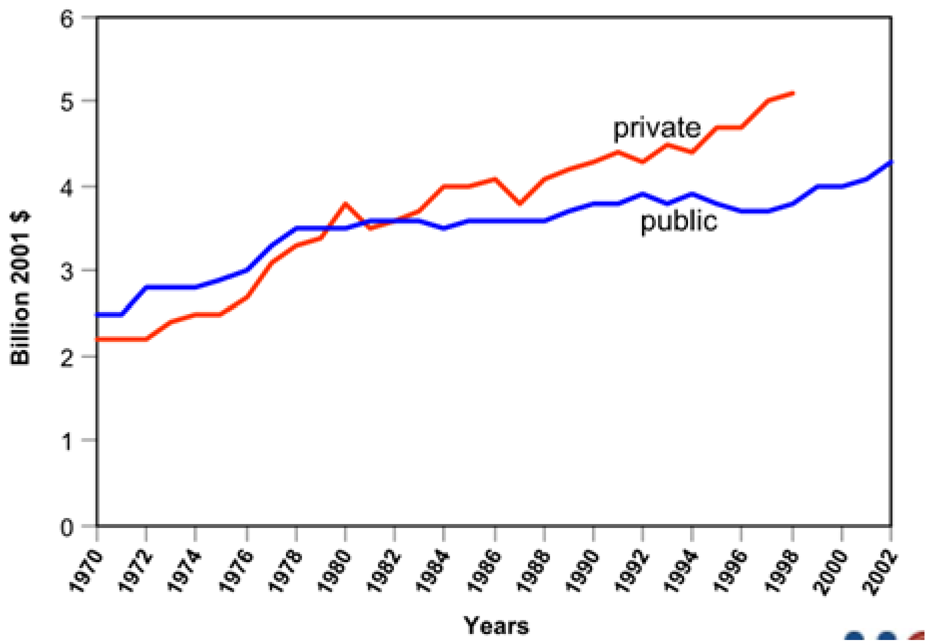

Figure 2.1. Public Versus Private Research (Klotz-Ingram & Day-Rubenstien, 1999)

The agbiotechnology industry is one of the most concentrated industries in the world. Although there are hundreds of smaller firms, the market is controlled by six large multinational companies: Dow, DuPont, Monsanto, Bayer, and Syngenta(Runge & Ryan, 2003). This high market concentration is caused in part by large research and development as well as regulatory approval expenditures.

Economics of Breeding

Wheat breeding is an expensive and lengthy process. A new variety can take as long as 17 years between initial cross and release. Additionally, several years are needed for growers to adopt and plant the new varieties. (Barkley, 1997) conducted an economic analysis of the Kansas State University wheat-breeding program from 1979 to 1994. Although comprehensive costs averaged $3.8 million per year, there was an increase in wheat production of more than 1% per year. The wheat-breeding program averaged a benefit-to-cost ratio of 11.95. This result means that nearly $12 was earned by Kansas wheat producers for each $1 invested in varietal improvement. This number does not include spillover of Kansas varieties into neighboring states, providing further benefits. On a more global scale Lantican, Dubin, and Morris (2005) found that CIMMYT's investment in wheat breeding provided returns greater than $50 for every dollar invested.

Although developing new wheat varieties has been shown to be a high-return investment, it is not economical for all breeding programs to invest in every technology. The research and development that have low capital-investment requirements, such as physiological selection and improved statistical analysis, are likely to be more widely adopted in the early years than more capital-intense or higher-cost technologies (Brennan & Martin, 2007). It is even probable that those new and higher-cost technologies will not survive in a world of increasingly limited public funds and commercially driven private programs.

With the development of any new product there are tradeoffs. In the case of new variety development, there is a tradeoff among yields, disease resistance, and wheat quality. Dahl, Wilson, and Nganje (2004) tried to solve this problem by creating a model that can be used to compare and rank *ex ante* values of varieties to growers and end-users separately and jointly under risk considerations. Their stochastic dominance criteria and statistical results showed that dominance varies depending on what wheat-grower and end-user values are utilized; this result confirms that there are tradeoffs among varieties. These results could then be used to identify future breeding opportunities.

There has also been research done about the value of certain wheat characteristics, including drought tolerant wheat. Shakya, Wilson, and Dahl (2012) developed an analytical model that valued the different phases of development using a stochastic binomial model of real options. The value of drought-tolerant wheat was found to be in the money (ITM) at each phase of development. The variability of NPV diminished at each phase looking forward, as the risk associated in subsequent development stages decreased. A trait that is more likely to be discarded in early stages because of the high probability of being out of the money (OTM) becomes increasingly ITM as the developmental stages pass. The use of the option tree provides leverage for management to choose the option to wait by recognizing market conditions and to still receive value for the trait by continuing in the future. This flexibility is absent when investment decisions are made solely on NPV.

Wheat Breeding

As previously noted, wheat breeding can be broken down into several stages, from F1-F8, after which are the advanced lines and yield trait stages. For the purposes of this thesis the selected bulk method of breeding utilized at CIMMYT (Van Ginkel, Trethowan, Ammar, Wang, & Lillemo, 1998) is used. Traditional wheat-breeding methods require up to 12 years of research to successfully produce a new wheat variety.

F1: A simple cross is made producing about 2,000-2,500 simple crosses per cycle.

F2: These populations are larger than the F1 population, consisting of about 750-1500 plants per cross. They are placed in 4-6 rows that are about 10-15 cm apart. A disease epidemic is introduced into the population. The poorest F2 populations (10-15%) are discarded before any within-population selection.

The remaining F2 populations are selected based upon the following traits:

- Agronomic type
- Synchronous tillering
- Appropriate height
- Healthy leaves
- Durable disease resistance
- Preferred spike type
- Large spike
- Good fertility
- No shattering
- No lodging
- Stay-green character
- Desired maturing

Several spikes (2-5) of the remaining selected plants are harvested, totaling 30-60 spikes per cross, and threshed in bulk. The seed is observed for grain-filling characteristics, plumpness or boldness, lack of disease and yellow berry, and other markings. About 30-50% of the entries are discarded.

F3: The previously selected F2 seed is planted in a row, 2 m in length, at a normal seeding rate (80-100 kg/ha). The reasoning behind this method is that the plants can develop in a similar manner as they would in the farmers' field with few tillers and in close proximity to neighboring sister plants.

The selected F2 population only generates one F3 seed lot and, hence, only one F3 plot. All F3 materials are planted under well-watered conditions. Again, an epidemic of the prevalent diseases is created. These lines are progeny tested in the greenhouse for stem rust resistance by seeding inoculation with a composite of stem rust. The poorest F3 populations (10-15%) are discarded prior to any with-in population selection. The best individual plants within the F3 populations are selected based on the same agronomic type as detailed in the F2 section. Similar to F2, several spikes (2-5) of the remaining selected plants, totaling 30-60 per cross, are harvested and threshed in bulk. The seed is visually observed during this time, and poor populations are discarded. The process generates the F4 seed for the next generation.

F4 and F5: In the F4 and F5 generations, the F3 methodology is largely repeated. The main difference is that the seeding rate per plot is increased (by about 50% relative to F2 and F3). During the F4 and F5 generation, the plants should develop more or less the same way they would in commercial conditions, although individual plants should still be visible. This method is to make sure individual plant selection can still be practiced without any major difficulties. Epidemics of the prevalent diseases are again created. The number of populations retained decreases from the F4 to F6 generations.

F6: Harvest differs for the F6 generation, but the planting methodology is the same one used for the F3-F5 generations. The plants are, once again, selected based on good agronomic type and response to the created disease epidemic. During the F6 generation, individual spikes from the best plants are harvested and kept separate for threshing and planning. The total number of spikes selected per cross is considerably large (20-100) because significant genetic variability may still be contained in the F6 population. No seed selection is done during this time because the seed quantity obtained from individual spikes is low. The F7 generation is planted as head rows during the next cycle.

F7: Thousands of entries are planted in a small area using head-to-row planning in a 1-m triple or double row. Again, an epidemic is created and released of the prevalent diseases. The best, uniform lines are selected and harvested in bulk. The seeds that are selected are then promoted to advanced lines (ALs).

Certain F7 plots have been proven to contain very attractive plants that are not uniform enough to enter the ALs and further yield testing. This process can be explained by the fact that the modified pedigree/bulk selection practiced on the later generations (F4-F6) allowed unstable plots to be discarded. In the selected bulk method, one plot represents the cross in any generation. This result means discarding the cross on the basis of the lack of uniformity that would result in the loss of an entire cross. Therefore, F7 plants that appear promising but lack uniformity are reselected by harvesting three individual spikes which become F8 head rows.

F8: The head rows in F8 are planted in one 1-m triple or double rows. Similarly to F7, an epidemic of prevalent diseases is created and released; uniform lines with an outstanding agronomic type are selected. Seed selection occurs after harvesting. As in F7, the remaining entries are promoted to advanced lines (ALs).

Advanced Lines (AL): Solid 1-2 M strands of the newly bulked F7s or F8s are exposed to an epidemic of prevalent diseases in observation for agronomic type and disease resistance. The best AL entries are then moved to first-year preliminary yield trails (PYT).

Preliminary Yield Trials (PYT): These lines are planted and analyzed according to specific, unreplicated statistical designs to eliminate the lowest yield 50-60% of the yield distribution. Joint data about absolute and relative yield, agronomic type, uniformity, lodging, and disease resistance are used to make the final selection decisions.

The end stages, both for the advanced lines and preliminary yield trials, are the most labor intensive and costly. Because the needed results are very defined, these stages can take many years. For the purpose of this thesis, it was assumed that both stages take 1 year to complete.

In summary, the development of germplasm takes 8-15 years. A single cross is made at the F1 stage. In the F2-F8 stages, a disease epidemic is introduced to the population. The poorest populations are discarded before any within-population selection. The best lines are then selected using the previously noted characteristics. Advanced lines and preliminary yield trials are then done. The variety is then approved and released.

Value of a Plant's Genetic Resources

Centers of crop origins, also known as gene banks, contain different components and levels of genetic and cultural information about crops. Primary gene pools and agro-ecosystems at crop-origin centers contain different components and levels of genetic and cultural information: individual genes and their variants, genotypes, crop populations for wild and weedy crop relatives, farmer knowledge, and seed networks among farmers (Brush, 1996). The economic value of a plant's genetic resources is derived from human use, although human use can refer not only to food, fiber, and medicinal production, but also to aesthetic, ecosystem, and social support functions (Brown, 1991). Economists who assess the value of natural resources such as wildlife habitats and endangered species, have developed a "taxonomy" that may also be used to classify the value of a plant's genetic resources (Smale & Koo, 2003). As shown in Figure 2.2, the total value of genetic resources can be broken into two parts; use value and non-use value.

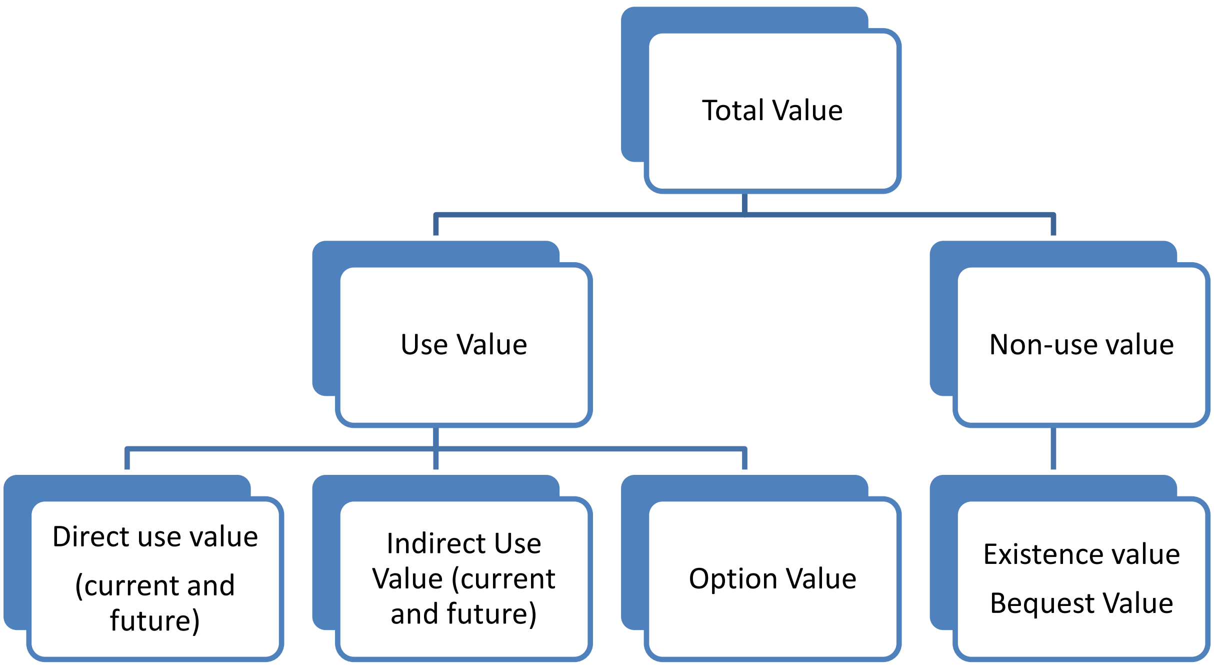

Figure 2.2. Taxonomy of Value (Smale & Koo, 2003)

While looking at the use value you see that it can be direct or indirect. The direct use value comes from the food and products to which the plant's genetic resources contribute. This value refers to the harvest and use of plans as part of a noncommercial, commercial, and/or industrial process. Indirect use value is the contribution of a plant's genetic resources to the surrounding ecosystems. These benefits result from biological resources without depending on harvest or consumption.

The other value listed is the option value. It implies the flexibility to deal with unexpected future demand for resources (Fisher & Hanemann, n.d.). This value is both social and private. The social benefit comes from the value of future generations having the opportunity to use the genetic resource to breed new crop varieties. For the future, The private option value is essential to meet production and consumption needs.

The satisfaction one gets from knowing that the germplasm exists, whether it is used, is the non-use value. The bequest value is the utility gained by knowing that future generations will have the opportunity to utilize the germplasm. These resources may have a high value because future generations may face different agricultural conditions than those at the present. This value is demonstrated by the turnover rate for different crop varieties. That rate depends on the available genetic resources. There is also the value of the germplasm existing and not becoming extinct.

Measuring the germplasm's value is more difficult. Stored germplasm largely exist in order to respond to future unforeseen changes. As a result, the expected future value, or the option value, is an important part of the total value.

We can, with some degree of uncertainty, calculate a present value for the expected future benefits derived from the direct use of germplasm for crop improvement with commercial agricultural systems. This process can be done by combining the probability of finding a useful material with its expected productivity benefit once it is found and incorporated in a new variety. Algorithms or numerical rules of thumb can be used to establish upper and lower limits for a variety's genetic contribution of a variety (Pardey, Alston, Christian, & Fan, 1996). Because of the time value of money, the time required to search for and discover useful genes affects the benefits received from the new germplasm.

In 1991, Brown was awed by how little economics could contribute to the valuation of genetic resources (Brown, 1991). Since then Pearce and Morgan (1994) valued biodiversity. Through their research they found that the total economic value of environmental resources consists of the use value and non-use value. The use value is made of a combination of its direct use values, indirect use values, and option values. The non-use values come from the bequest values and existence values.

Alternatively, Brennan et al. (2005) assessed the value of molecular markers for plant breeding programs. They found that the value of a molecular marker to a particular breeding program depends on the costs of the marker implantation, costs of alternative phenotypic-selection regimes, and implications for the other operations of the breeding program. The value of a molecular marker for a particular trait to an individual breeder depended on the objectives of the breeding program, the relevance of a particular trait in the key target regions for the breeding program, the closeness of the linkage between the marker and the desirable trait, the capacity to undertake phenotypic screening for the trait by conventional means, and the cost of phenotypic screening for the trait by other means.

Intellectual Property Rights (IPR)

Germplasm was once thought of a combination of characteristics. It is beginning to prove more sensible, for intellectual property purposes, to capitalize on plants not as varieties, but as genetic datasets (Janis & Smith, 2007). This idea is based upon a number of technological developments; the most obvious development is molecular markers. As early as the 1970s, seed companies analyzed plant protein data as a way to monitor genetic the purity of commercially important inbreds and hybrids. By the 1980s, tools became available to directly manipulate the DNA in a relatively easy manner.

In the past 30 years, improvements in science have allowed for genetic modification within cells to alter traits not available through traditional breeding. Along with the new traits, these achievements have led to new varieties at a lower cost and faster pace. These advancements have attracted private companies to invest in the seed industry. Along with the increased involvement of the private sector come improvements in intellectual property rights (IPR). Without outright acquisition, access to germplasm must now be obtained by patent licenses, plant variety protection (PVP), material transfer agreements (MTA), bag-label contracts, technology use agreements, or a trade secret (Wright, 1998).

Patent licenses are either exclusive or nonexclusive. Research licenses are also available at a lesser cost, but they only allow use for research, not for commercialization. If any innovations are achieved under a research license, they may be blocked by the license holder. This block leaves the innovator in a weak bargaining position.

Plant variety protection (PVP) gives the breeder exclusive rights to a new and distinct variety so that the breeder can develop it. This protection is given to the owner of a variety after it is proven to be new and distinct from other varieties and when it is genetically uniform and stable throughout successive generations. The protection lasts for 20 years. In the United States, the owner has exclusive rights to multiply and market the seed for that variety. The protection works by prohibiting a person from selling, marketing, offering, delivering, consigning, or exchanging variety without explicit consent from the variety owner. This type of protection is used for plants which have been developed through traditional breeding, not through genetic engineering.

Material transfer agreement (MTA) is a type of contract that allows for the transfer and use of breeding inputs for research or for commercial use. The material being transferred must have some independent means of protection, such as a patent or trade secrecy, to prevent the material being acquired by third parties. Generally, an MTA is a way of transferring material with “trade secret” protection.

Bag-label contracts are an additional means of protection if using the seed for breeding is found to violate an implicit contract that is written on the bag label. In recent years, Pioneer Hi-Bred International has sued some of its competitors. The company alleges that competitors’ selected self-pollinated seeds found in bags of Pioneer’s hybrid corn seed and used those seeds to breed competitive hybrids.

Over the past few years, technology use agreements have given the right to plant a given seed type on a specific area of land. Provisions could also include restrictions for the use of proprietary traits in the creation of new varieties.

In order to qualify for trade secrecy protection, a secret must be protected from acquisition by others. This option is considered to be feasible with commercial hybrids’ “in-house” parent line. Trade secrets are cannot be protected if commercial seed is sold to farmers.

A court decision in the United States, *Diamond vs Chakrabarty* (1980) started the momentum for patenting life forms, including plants. Later, the 1988 Harvard OncoMouse patent extended this decision to higher life-forms (and to a research tool). Also in the 1980s, gene fragments, markers and some intermediate techniques other inputs used in drug discovery and commercialization became patentable. Since then, other related legislation has encouraged universities and national labs that are responsible for research and development to patent their findings.

IPRs were originally initiated to create more innovations in the research industry. These rights can become a problem with crop research because of the researchers' cumulative work. Property rights can be shared among the creators of germplasm, cultivars, and gene sequences. When these owners get together, the negotiation process may fail. This problem is especially large where DNA modification techniques are used frequently. When too many intellectual assets come into play, negotiations break down because each IPR owner wants a share of the rents. This problem has been labeled as the "tragedy of the anticomons" (Heller & Eisenberg, 1998).

In a letter to the editors, Price (1999) shared the results of a survey about how available genetic stock is to universities. Of the 86 responses, from 25 universities and 41 about crops, "48 percent indicated that they had experienced difficulty in obtaining genetic stocks from private companies; 45% indicated that this had interfered with their research; 28% felt that it had interfered with their ability to release new varieties, and a shocking 23% reported that it had interfered with the training of graduate students" (Price, 1999). This result creates more incentive for NDSU to license the germplasm that is has available to make it just as easily available in the future.

IPRs have changed the nature of knowledge from being non-excludable to being excludable, therefore changing the nature of research benefits and research incentives. In her dissertation, Viktoriya Galushko looked at the incentives for innovations when such innovations are protected by Plant Breeds' Rights (Galushko, 2008). Throughout her surveys, it was found that the possibility of patenting does change breeders' behavior. Looking at the wheat and canola sectors, one could say that there is a hindrance to efficient knowledge dissemination and research whenever applying biotechnology on a large scale with private participation is concerned.

Literature Review for Real Options

When valuing an investment, managers can use net-present-value (NPV), discounted-cash-flow (DCF), or real options. The NPV and DCF approaches fail to capture dynamic risk changes due to management's ability to delay, abandon, reverse, or continue the proposed operating strategies when more certainty is achieved. Over time, uncertainty is likely to be reduced. As time passes, management is likely to have more information; therefore they can take steps to maximize the upside potential profit and to minimize the downside loss. A similar conclusion was made by Trigeorgis and Mason (1987) who wrote that "the 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."

Alternatives approaches for valuing investments that include simulation and decision tree analysis have been suggested as appropriate ways to reduce the shortcomings of DCF and NPV. These approaches would not be appropriate when valuing germplasm because they use a constant risk adjusted discount rate, which is appropriate only when resolved continuously at a constant rate of time. Most biotechnology investment decisions are contingent, and further investments are needed.

The aforementioned shortcomings can be explained by thinking of investment opportunities as bundles of “options” on real assets. The real-options approach is based upon the framework of the “option pricing theory”. In the world of finance, an option is the right to buy or sell the underlying asset at a specified price on or before a specified date. Using option pricing, the theory is that when there is uncertainty of an investment in the future, the flexibility to make decisions after resolution of some part of uncertainty becomes important and has value.

Real Options with Research and Development

When viewing the research and development in biotechnology traits, there is no set price, date, and quantity known about the future. Research and development is a risky venture. There is a certain risk and uncertainty associated with researching and developing of traits that should be treated like stock price movements in option pricing theory. Problems associated with valuing research and development options (as suggested by Paxson, (2001) include

- Identifying the stages of R&D management flexibility in action.
- Modeling the duration, dimension and diffusion process of the eventual R&D payoff values.

- Dealing with the unusual environment where R&D is budgeted and the expenditure consists of salaries and experiments occurring continuously in time rather than instantaneously at a point in time.
- Identifying the time-varying volatilities of the process and of the underlying eventual values.
- Including the possibility of success or failure of part or (or the entire) venture, which may also be time varying, in a real option model.
- R&D data are not always public, or even available within research enterprises, and often are not suitable as input for economic models.

Although there are the previously stated problems, the high volatility of research and developments output has an influence on the value of the option because high returns can be generated and because extremely low returns can be avoided by reacting appropriately to changing conditions. Real options have been applied to and studied with research and development in specific and general applications.

Jensen and Warren (2001) valued research and development in the service sector using the real-options theory. They went on to describe that the lifecycle of an e-commerce project can be split into three stages. The first stage is the research phase, during which investments are made for research and market development. The second stage is the development stage which is characterized by the business unit's expenditure. The final stage is the implementation phase which is characterized by a commitment to both an initial expenditure and ongoing expenditures during the project's life.

The compound call option is used when solving the life cycle problem through real options. The first part of the option is to launch the project's developmental phase project. This option, in turn, buys the option to advance to the implementation phase.

Real Options in Agriculture and Biotechnology

Little work has been done in the field of pricing and valuing the agbiotechnology development process. The studies that have been conducted focus on the benefits of genetically modified (GM) crops and varieties as well as their rate of adoption. The studies focus on traits that are certain and predictable, as well as visible to users. These traits have been the main marketing theme for various firms. Studies that compound options to model changes in the food business have also been done (Briggeman, Detre, & Gray, 2004).

(Nadolnyak & Sheldon, 2003) valued international patent rights for agricultural biotechnology using real options. They found that biotech companies were prevented from entering the developing counties by poor enforcement of intellectual property rights and high entry costs. Their data also suggested that biotech companies recoup most of their R&D expenses from marketing their products in the industrial part of the world, despite strong consumer and government opposition. Overall, the option to delay entry is higher in developing counties because of the high volatility of the returns from marking GM crops.

The optimal timing of investing in an irreversible project with uncertainty was examined by McDonald and Siegel (1986). As mentioned previously, the decision to adopt GM wheat is irreversible and has externalities that affect the social desirability. Their conclusion was that it is almost always optimal to defer investing until the present value of the projects cash flows is greater than the cost of investing by some positive amount. Their research was applicable to analyzing environmental issues, industrial organizations, and investment theories.

The optimal time to license an agbiotechnology product, specifically GM wheat in Canada, was researched by W. Furtan, Gray, and Holzman (2003). They argued that the adoption of GM wheat is irreversible because the seed is easily spread to neighboring fields via transport on farm equipment or via birds, wind, and water. This spread of seed leads to two negative externalities. The first one is that the spread of the new variety into non-GM fields impacts both the adopters and non-adopters of GM wheat. The second externality is the potential loss in market returns due to lack of effective trait segregation.

The value obtained by postponing an irreversible investment can be equated to the value obtained from holding a call option in the financial markets. The call holder, and decision maker, has the option to invest now or postpone until a later date. If GM wheat becomes more socially desirable, the value of the option increases. 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. The value to wait for more information is eliminated if the option is exercised.

New random genetically modified traits for corn were studies by Shakya, Wilson, Dahl (2013). An ex ante value of a GM trait in corn with random characteristics was estimated using a stochastic, binomial, real-option model. Technically, the authors used a compound-call option with the option to continue, wait, or abandon at each developmental phase. Results indicated that there was a small chance that the option would be out-of-the-money during the discovery phase. The value was expected to be in-the-money during all other phases.

Drought-tolerant wheat was valued by Shakya, Wilson and Dahl (2012). Using a stochastic, binomial model of real options, they developed a model that could be used to analyze the value of GM traits at different phases of wheat development. The results indicated that the value of drought tolerant wheat, with the use of GM technology, was in-the-money at each development phase. The value of GM drought tolerant wheat exceeded that of drought-tolerant corn (Shakya, Wilson, and Dahl, 2013).

Previous studies used real options to examine the value of GM traits in wheat (Carter, Berwald, & Loyns, 2005; I. M. Flagg, 2008; W. H. Furtan, Gray, & Holzman, 2003). These studies analyzed decisions from a public-sector perspective and were modeled as post-development timing options which were irreversible. Those values were then derived using the Black-Scholes model. The authors primary concern was the risks involved in the post-product development phase (e.g., the commercialization phase).

In financial terms, the option to exercise or delay exercising of an option is characterized as a timing option. The investor has the option to delay the investment. Delaying has value because it gives the market a chance to reduce some uncertainty associated with the investment. In the case of GM wheat, the potential for negative externalities is reduced over time. These externalities give the time to delay more value.

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

This model differs from previous work in various ways. GM wheat was studied by McDonald and Siegel (1986) and W. Furtan et al. (2003). They were only looking at GM wheat and its externalities. This model examined non-GM wheat and measured the value it is adding. Shakya (2012) and Flag and Wilson (2008) analyzed the five developmental stages of a typical GM trait as a "growth option" that was portrayed to be similar to a call option, where each subsequent option depended on reaching certain milestones. This model is also very similar in the fact that certain milestones have to be reached before the next stage can begin. The difference is that this model requires 11 generations instead of 5 stages and uses the varieties NPV. Guthrie (2009) used compound growth options to determine whether to "continue" or "wait" on an investment. For this thesis, this model was expanded to add up to 11 generations and used the NPV determined by @Risk.

3. THEORETICAL MODEL

Introduction

Various methodologies are available to value new technologies when future returns are uncertain. The simplest form of these valuation tools is net-present-value (NPV), moving to more complex forms such as the use of real options. One wants to reduce uncertainty as much as possible. As mentioned previously, none of the current methodologies are able to foresee all the risks associated with possible scenarios. A firm may invest in a new and improved type of germplasm that could prove to be undesirable after completion, 10 or more years after the initial investment. This same germplasm may in turn be profitable if licensed or sold to another firm during the development stages. Another alternative is that a firm may under-invest in a new type of germplasm that could become very profitable in the future; in turn, the firm will not receive the maximum amount of benefits.

Using a single methodology cannot allow people to make better decisions when future investment returns are uncertain. Utilizing a combination of quantitative, analytical, and simulation tools, a decision maker can be better informed. A distinct conclusion can be made using these tools either simultaneously or individually. The conclusion made by the decision maker about whether to invest in a new variety will, ultimately, depend on the tools used to validate the decision. This choice is even more important when the expenditure is irreversible, as is the case for most research investments.

Using real options captures the risk and options in the technology development process. Decision makers have the choice to halt, defer, abandon or continue with their investment. As time passes, more uncertainties become known, as do additional externalities for the investment. With the reduction of uncertainties comes additional value for the management because this reduction helps make better investment decisions. A decision maker has to determine whether to invest in a new variety. This choice will be very costly to the firm and is irreversible once it is made. As an example, today's consumers are very interested in low or gluten-free foods. This interest was not the case 10 or 20 years ago. Many firms may not have chosen to invest 5 years ago, but seeing today's demand, they are choosing to continue with their investments.

In order to be economically efficient, one must find an optimum allocation of scarce resources. Management firms must do this same allocation regularly. The most basic valuation methods include the neoclassical approaches. The two common variants of marginal analysis are the user cost of capital and Tobin's q. There is also a review of DCF and the decision-tree framework.

Traditional Valuation Methodologies

Neoclassical Approach

The basic neoclassical models are based on the theory of marginal utility. These models mostly deal with the marginal cost of production. The neoclassical approach suggests that a manager should chose to invest if the marginal cost of capital is equal to or less than the marginal return on the invested capital. The decision to invest is dependent upon the added marginal return if the firm produces one more unit of a product. Two common marginal economic variants for this theory 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, the 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, a firm's short-run investment behavior m depends on "the time form of lagged response to changes in the demand for capital" (Eisner & Jorgenson, 1969).

The desired amount of capital stock, K^* , is defined as a Cobb-Douglas production function with the 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 new projects are initiated each period until the firm reaches its 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 the marginal investment to its capitalized value (Hubbard, 1994). The second variant is 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, the marginal efficiency of capital, income, wealth, and the price of currently produced goods. The investment decision is based upon specific criteria for the value of m/p or, more simply, q. These decisions are ranked as:

$q > 1$, The firm should invest.

$q < 1$, The firm should not invest and should reduce its capital stock.

$q = 1$, The 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.

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

Discounted-Cash-Flow

In business operations, firms normally receive cash flows at distinct points in time; therefore, the analyst must adjust cash flows to make them equivalent to each other. The time value of money is a basic, yet essential, part of DCF. In order to put cash flows that originated at different times on an equal basis, a firm must apply an interest rate to all flows so that they are expressed in terms of the same time point. The two most common DCF models are net-present-value (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 the project
R_t	=	Cash inflow in period t
O_t	=	Cash outflow in period t
k	=	Discount rate (cost of capital)

The discount rate, listed as k, is often determined by the opportunity cost of capital or, in simpler terms, the cost of capital. If the analysis indicates that any given project has a positive NPV, the firm should continue with the investment. However, because capital is limited, the firm can rank projects with NPV > 0 and select the project with the greatest value to the firm. Alternatively, if the NPV of a project has a negative NPV, the firm should chose not to invest. Lastly, when a project's NPV 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 for 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. This process is represented mathematically as:

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

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 situation is not always the case.   The recommendations could be different when the initial costs for two proposals differ or cash flows are received in different income streams; NPV and IRR will provide conflicting results.

One of the many weak points of DCF is the method to account for risk in the analysis. Typically, risk is measured by using a risk adjusted discount rate (RADR) or certainty equivalence. RADR is the most frequently used risk adjustment method (Keat & 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 considered to be an exact science and are left to the decision maker's judgment.

The use of certainty equivalence is another common method for risk adjustment. There are at least as many short comings with this method as with 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 & 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 decision 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 & Finnerty, 1997). Decision trees essentially add subjective probabilities to the traditional DCF analysis. While using this approach the decision maker acknowledges that future cash flows depend on future actions and choices. Decision trees are commonly framed graphically as shown in Figure 3.1. In this example, a firm is confronted with a decision to either invest in the production of a new good or to not invest. At the end of the tree, β and α represent the respective payoffs for either fast or slow adoption of the new product, and p is the probability of fast adoption.

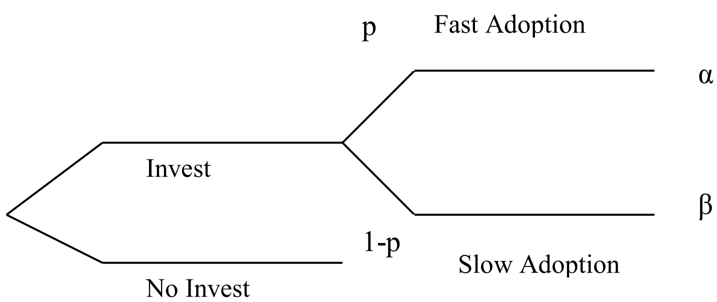

Figure 3.1. Decision Tree Framework

Typically, the payoffs for decision trees are the expected monetary payoff, the 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. Therefore, 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 can be useful, but incomplete. Many investments incur various development stages, which provides multiple and continuous decision making and requires 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 option theory, traditional methods can provide a more accurate insight about strategic and investment decisions.

Details of Financial Options

The most basic option types are the call and put options. The call option gives the owner the right to buy the underlying asset at a specified price on or before a set date. If, at expiration, the value of the underlying asset is less than the strike price, the option is considered to be "out of the money" and will not be exercised. Alternatively, 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, Kane, & Marcus, 2004). The profit for the option buyer (the 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 holder's profit can be represented graphically as shown in Figure 3.2,

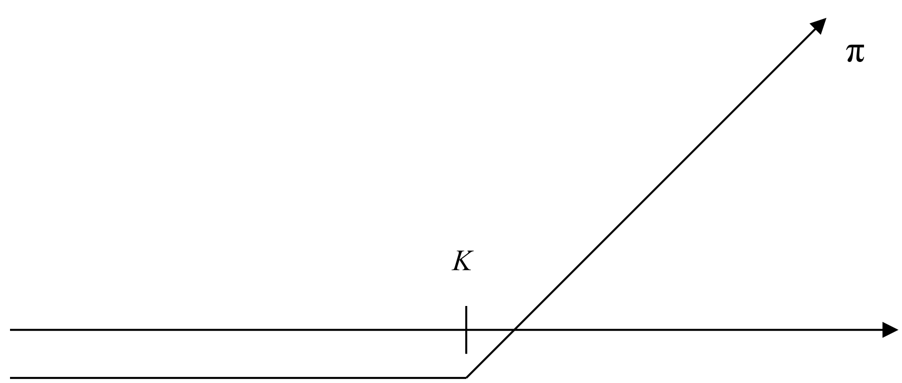

Figure 3.2. Profits for a Long Position in a Call Option (Damodaran 2005)

As long as there is a long position in an option contract, there must also be a short position. The call-option writer assumes the short position for each call option. According to Hull, (2005), the call-option writer receives cash upfront for 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 call-option writer is anticipating the value of the underlying asset to be flat or negative.

A put option gives the buyer 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 buyer’s profit for a put option is $MAX = (K - \omega - S_t, 0)$. The holder’s profit for a put option can be represented as shown in Figure 3.3.

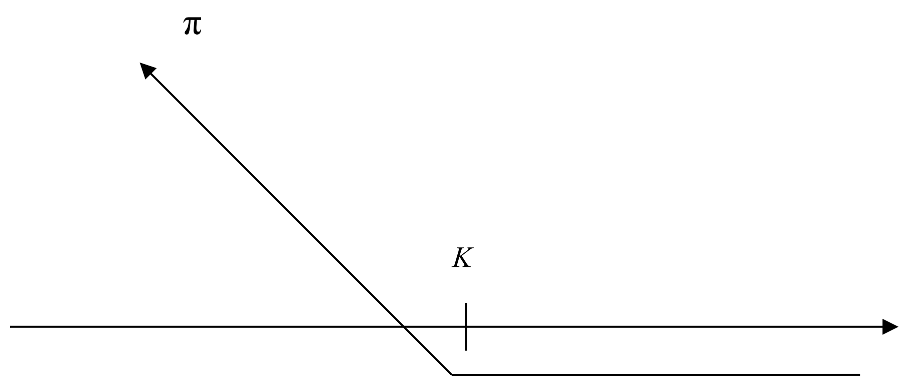

Figure 3.3. The Holder’s Profit for a Put Option (Damodaran 2005)

The put-option writer is anticipating either an unchanging market or an increase in the underlying asset’s value. As with the call option, the writer 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 option-contract writer is exposed to a considerable amount of loss. The call-option writer could, theoretically, incur an infinite loss. There is no ceiling for 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.

There are many other types option contacts that are commonly referred to as "exotic" options, although American and European calls and puts are the most common option types. A European call option only allows the holder to exercise the option (in the case of continue or wait) on the expiration date. An American call option allows the holder to exercise the option at any time during its life. For the purpose of this thesis, we use American options. The new option types have been created primarily by the demand for customized options which provide various alternative benefits that are not found in traditional contracts. As an example, returns typically depend on the final price, but Asian options depend on the average price of the underlying asset. Another exotic option is the look-back option where the payoff depends, in part, on the minimum and maximum price of the underlying asset during the life (Bodie et al., 2004).

Real-Options Approach: Empirical Analysis

Put and Call Parity

Put and call parity can be determined 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 to yield a 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

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

In the equation, *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

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

Now, N represents the profits from the above mentioned 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 prices are equal to the present value of borrowing at the risk-free rate of interest. Therefore,

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

Black-Scholes Model

The Black-Scholes model was primarily designed to value European call options with no dividend payments. Therefore, early exercise and dividend payouts have no effect on the call option's value. 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 option's life

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

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

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

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

Binomial Pricing Model

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

Hull, (2005) explains Figure 3.4 as a sequence of steps. First, consider a stock where the current price is S_0 and an option of the same stock whose current price is represented as f. The stock can either move up to S_0u or down to S_0d at time T. The proportion of upward movement is u-1, and the proportion of downward movement is 1-d. If the price of the stock moves up, the payoff for the option is f_u; if the price of the stock moves down, the option payoff is f_d.

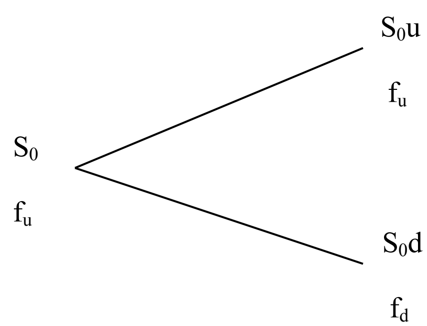

Figure 3.4. Stock Price Movements Represented in a One-Step Decision Tree (Hull 2005)

Assume that there is a long position in the underlying shares of stock, and a short position in one option 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 contract creates a riskless portfolio and must earn the risk-free interest rate. 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,

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

where

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

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 previously (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.

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

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

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

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

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

$$f = e^{-r\Delta}[pf_{u} + (1-p)f_{d}]$$

Substituting from the first two equations into the third, we get

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

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 interest rate (Hull, 2005).

Research and Development with Real Options

Investing in research and development can be thought of as investing in future opportunities: real options can be used to value such opportunities (T. Luehrman, 1998). The thinking behind financial options is extended to real assets by using real options without imposing any obligation for further to investment in a project.

The research and development of a new wheat variety lends itself to the application of the real-options framework because the development process is staged and because there are measurable risks and uncertain outcomes for 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 of the eight generations.

The following section introduces the most important types of real options. In addition, there is an overview of the real-options valuation methodology which includes the adaptation of the Black-Scholes model to price 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 & Kulatilaka, 1999); options 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 real-option types, but three are of particular interest when analyzing research and development investments. Timing options, typically, occur when the decision maker has the option to delay the investment. In the end, the decision maker hopes that the final cash inflow will be valuable enough to justify funding the initial cash inflow. The time delay has value because the decision maker is able to wait in hopes of resolving some uncertainty associated with the investment.

The abandonment option arises when firms have the option to stop the production or the research and development for products where the market opportunities have diminished. In some cases, the cost of abandoning the project is offset by the project's salvage value. The abandonment option is often used with the development of a new germplasm. For example, after the discovery stage of development, the germplasm enters the proof of concept stage where decision makers attempt to forecast the 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, eliminating extra costs for a commercially doomed product. Abandonment options are similar to a put option for a common stock.

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

While looking at research and development investments, it is good to look at the time-to-build-option which includes staging the 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.

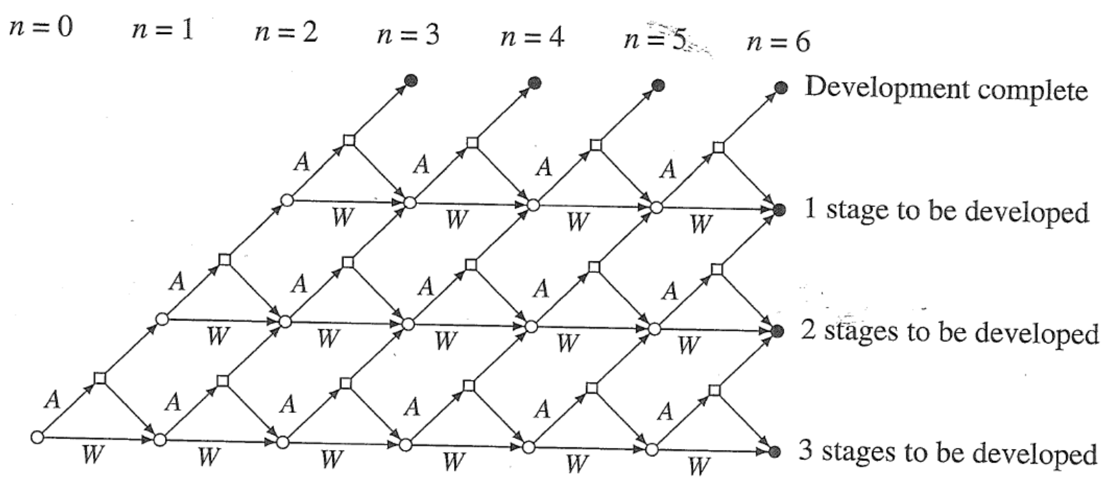

Figure 3.5. Recombined Option Tree (Guthrie, 2009)

Another type of option is the compound option. An example is shown in Figure 3.5. Using compound options involves a project that starts in one stage and moves through a specified sequence of statuses. The order of the sequence is fixed, but the dates at which they occur are influenced by the decision maker. The change from the first position to the second one is completely irreversible and can only occur when the decision maker chooses. The subsequent change from the second stage to the third is completely irreversible as well, and only occurs when the decision maker chooses. The project generates one cash-flow stream as long as it stays in the first state, another when it is in the second state, etc. The project generates different cash flows each time the decision maker tries to change it from one stage to the next.

Real Option Valuation Methods

The tools developed to value financial options can be useful in valuing the real options embedded in most investment projects. Because real options are more complicated than basic financial options, it is crucial to simplify real-option analysis to fit the financial models. As with all valuation tools, the purpose of real-option analysis is to assist in the decision-making process, not to 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 (T. Luehrman, 1998). One can map an investment opportunity onto a call option which uses the same value drivers as the Black-Scholes model. The present value of a project's operating assets to be acquired, represents the stock price; the cost required to acquire the project's assets is represented by the exercise price; the length of time the decision can be deferred represents the time to expiration; the time value of money represents the risk-free interest rate; and the level of risk associated with the project assets represents the variance of returns on stock.

Table 3.1. Map of Investment Opportunities Onto a Call Option (TA Luehrman, 1998)

Investment Opportunity	Variable	Call option
Present Value of assets acquired	S	Stock price
Outflow to acquire assets	X	Strike price
Time of deferral	T	Time to expiration
Time value of money	r_f	Risk-free rate
Riskiness of project	σ^2	Variance of returns

The value of the underlying asset affects both the call and put options in various ways. For call options an increased value for the underlying asset leads to an increased value for the option. Conversely, an increased value for the underlying asset has a negative effect on the value of a put option (Damodaran, 2005). Luehrman (1998) creates an option space by 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 it. In Figure 3.6 NPV_q is referred to as the value-to-cost ratio. When the value-to-cost metric is between zero and one, the project is worth less than it costs; when the metric is greater than one, the project is worth more than it costs.

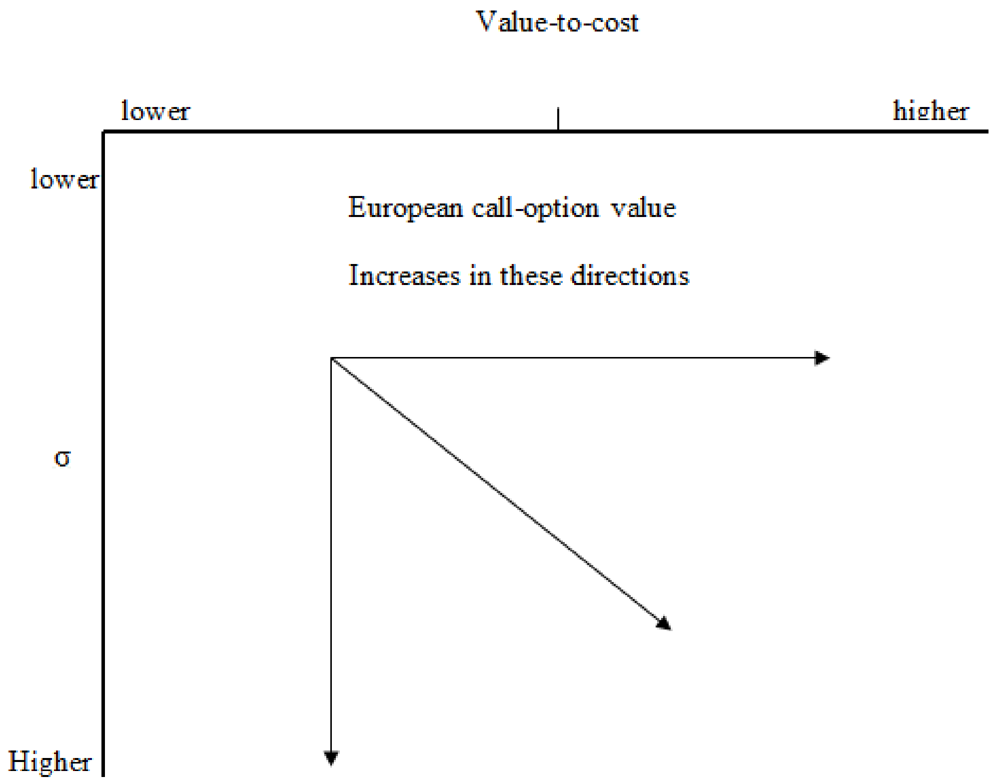

Figure 3.6. Luehrman's "Option Space"

The second determinant of an option's value is the variance in the underlying asset's price. The second metric is casually referred to as the option's volatility. This metric measures how much things can change before the next investment decision must be made. The volatility metric is determined by two factors. The first one is that the uncertainty of the asset's future value is captured by the variance per period of asset returns. The second one is that the length of time the investment can be deferred is determined by using the option's time to expiration. A higher the variance in the value of an option leads to a greater the option value. Although counterintuitive, higher volatility means that there is a greater chance of the value at expiration being either very high or very low. Because the maximum loss is the option premium, the potential gain from uncertainty overshadows the potential loss. This result is true for both call and put options (Hull, 2005)

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

Copeland and Antikarov 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. Understanding the path these values take over time using historical data, if available, or using management estimates. Step three creates a decision tree that can be analyzed to identify the places where management possesses managerial flexibility. Step four then uses real-option valuation techniques, such as the Black-Scholes or binomial model, to determine the option’s value. The option’s value is than compared to the option’s cost to determine whether to make the investment.

Similarly, Amram and Kulatilaka (1999) developed a four-step process to design and solve real options. The largest source of error during real-option analysis is that the application is poorly framed. Therefore, the first step in this process is to frame the application. The first step includes five critical elements that must be incorporated to develop a good application frame for a sound analysis:

- The decision: what are the possible decisions; when might they be made; and who is making them?
- The uncertainty: identify the evolution form for each source of uncertainty and lay out any cash flow and/or convenience yields.
- The decision rule: create a simple mathematical expression
- Look to the financial markets: Which sources of uncertainty are private, and which ones are market priced? Is there an alternate application frame that more effectively uses the financial market for information?
- Review for transparency and simplicity: who would understand this application frame?

The second step is to implement the option valuation model that is created specifically for the application's specifics. The primary component of step two is establishing the model's inputs by calculating the current value of the underlying asset, cash flows, and volatility for each uncertainty source in the model and obtains data about the risk-free rate of return. Once inputs are established, it is time to select an option valuation method (Black-Scholes etc.) and to obtain the numerical result.

The third step is to review the outputs from the option valuation. These results provide several conclusion types, which include critical values for strategic decision making, as well as findings that help quantify the investment's risk profile. The fourth step is to redesign the model if necessary.

Summary of Real Options and Implications

The choice to invest in germplasm can be implemented flexibly through deferral, abandonment, expansion, or in a series of investments. The more traditional methods of validation, including discounted cash flow, fail to capture all future opportunities that create value, thereby resulting in an underinvestment in research and development. Because the real options approach applies the financial options theory to real assets, it is more appropriate because this model views a research-and-development project as an initial investment that creates future growth opportunities.

Although there are numerous types of real options available, three are of particular interest for analyzing research-and-development investments: the timing, abandonment, and growth options. Because the development process has stages and each stage has measurable risk and uncertain outcomes, these options relate well to research and development. When using real options, the value of profitable projects is maximized, and investment in unprofitable ventures is minimized. All of these things are done by allowing management to modify course as market dynamics shift.

4. VALUING GERMPLASM: REAL OPTIONS METHODLOGY

Introduction

Real options are ideal for valuing projects where managers are flexible enough to adapt to changes in market dynamics. Developing a new variety involves risk and uncertainty in terms of investment, time, and returns. These risks make it imperative for policies to establish guidelines that attract germplasm investments that are expected to be of value for the public. A firm's management must also decide whether to invest in these projects, as well as making decisions about whether the germplasm is worth commercializing or if the firm would be better off selling the germplasm to some other company during early stages. This thesis uses the real-option methodology to evaluate germplasm as an option value at various development stages. This approach is used to help managers decide the best possible option if they make a certain choice that day. The real-option methodology is also useful in comparing different pathways and is, thus, better at exploiting the potential cash return from current investments.

Chapter 3 outlined the framework and application of real options. Developing germplasm is considered to be a compound growth option where technical or marketing milestones must be completed before management can exercise the option to invest further in the project. The first section of this chapter outlines the model framework and its objectives. The second section identifies data sources and distributions. The third section is a brief discussion about the stochastic simulation procedures using @Risk. Sensitivities for the key random variables are discussed briefly in the last section.

Germplasm Development and Wheat Varieties

Developing a new variety is an irreversible investment that involves a stepwise process that is spread over many years. Each generation has a certain percentage of lines that are kept and discarded. After the completion of a particular step, management has the opportunity to make a decision about investing in the following step. For simplicity's sake, it is assumed that the uncertainty associated with fixed cash flows is resolved at the completion of each step and that the decision to is made before subsequent phases begin. To better understand the uncertainty and the inherent opportunity available to management, the overall process from identification of a potential economical germplasm until it is commercialized can be categorized by the different generations shown in Figure 4.1. To start the process, two lines are crossed. This cross is then moved to the F1 generation.

There are two possible options that will be modeled in this thesis, to "continue" or "wait". As defined in the binomial option approach, each option is actually the "option value." At every stage of development there is always the option to wait until the option expires.

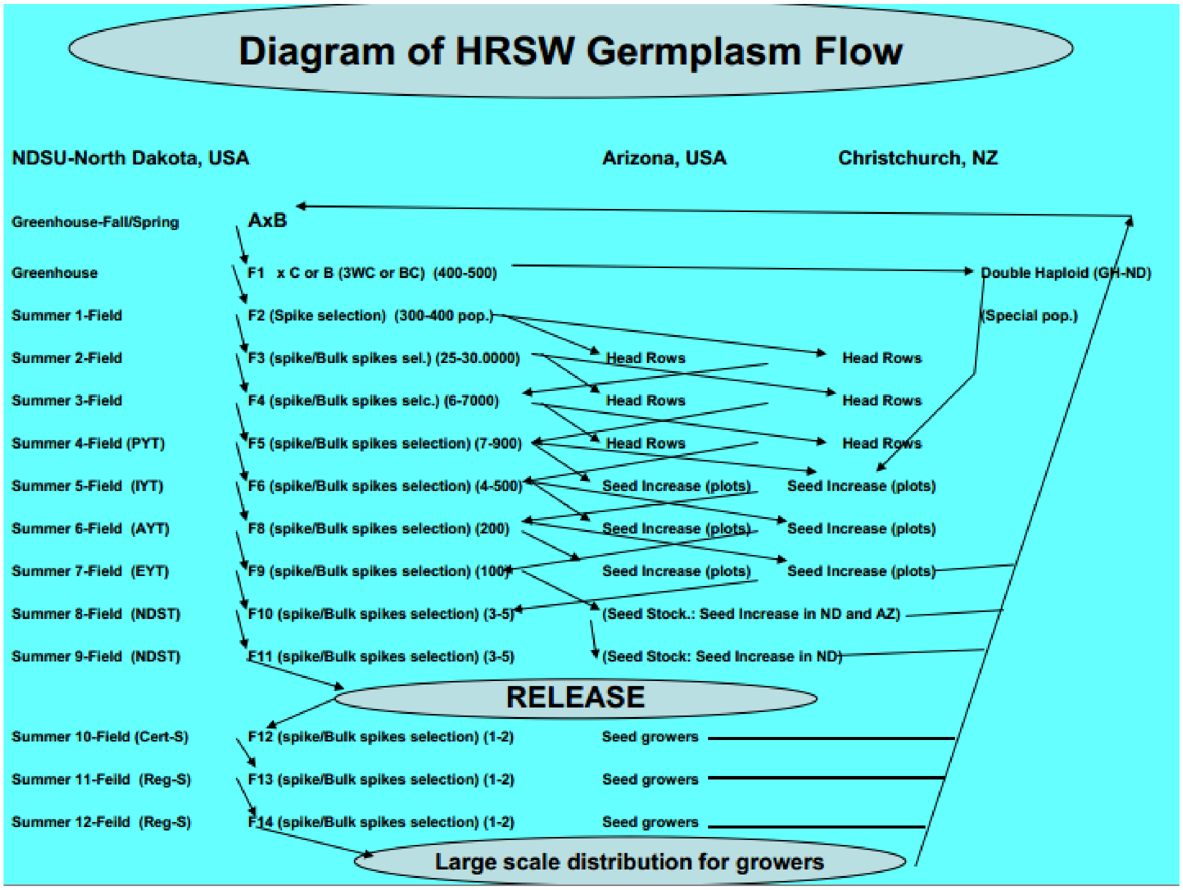

Figure 4.1. Diagram of HRSW Germplasm Flow (Mergoum, 2005)

Varieties of Wheat Analyzed

This thesis looks at two varieties of wheat: Glenn and Faller. At the time of release, Glenn was considered to be better in quality and was developed for western North Dakota. Faller was improved quality as well as substantially increasing the yield and was developed for eastern North Dakota. The two varieties were released by the North Dakoga Agricultural Experiment Station (NDAES) in 2005 and 2007 respectively. Both varities were based on crosses that were initially made in 1997. Glenn was released because it combines a very high level of resistance to Fusarium head blight (FHB), with high yield grain volume and excellent end-use quality (Mergoum et al., 2006). Faller had very high yield with good end-use quality as well as resistance to Fusariaum head blight and leaf diseases (Mergoum et al., 2008). When comparing the two varities, Glenn was a step change in quality and disease resistance, whereas Faller had greater yields but not as great of quality and disease resistance.

Dahl-Wilson Model

Dahl and Wilson developed an unpublished and forthcoming model to provide a value estimate for Glenn and Faller. An ex-ante comparison was used. Data and/or data distributions at the time of release were used. Analytically, the model was defined as follows:

$$V = Ac \cdot (\Delta Y \cdot P + \Delta Q \cdot Pro_{Prem} + \Delta DON \cdot DON_{Discount} + \Delta TW \cdot TW_{Prem} + \Delta E \cdot E_{prem} + \Delta A \cdot A_{prem}),$$

where t= year t, derived individually for each year; Ac is the acres planted by state; P is the seasonal average price; and Pro, DON, TW, E, and A are all premiums or discounts, respectively, for protein, DON, test weight, flour extraction and absorption.

The variables are defined by using Δ which is the change relative to incumbent varieties. ΔY is the yield difference. ΔQuality is the protein level. ΔDON is the change of the estimated DON level. ΔTW, ΔE, and ΔA are respective changes in test weight, flour extraction, and flour absorption.

The values for the comparison were derived from data available at the time, or release and market variables were defined as probability distributions and were then treated as random. The model was then transformed as follows:

$$V = AC \cdot (\Delta Y \cdot \hat{P} + \Delta Q \cdot \widehat{Pro}_{prem} + \Delta DON \cdot \widehat{DON}_{discount}).$$

In this case, the model was adopted as follows:

- Acres planted were the actual plantings in year t.
- ΔY, ΔQ and ΔDON were from the release data and treated as known.
- P, Pro_{Prem} and $DON_{Discount}$ were treated as random variables.
- Values attributable to test weight, extraction and absorption were excluded due to the fact that the data were not reported at the time of release.

Using 10,000 simulations in @Risk, the mean and standard deviation values from these results were then put in a real-option model. The NPV or V was used as the value at time 0. Alternatively, royalties, rather than valuations, were used for a comparison as a sensitivity analysis.

Royalty Structure

Germplasm returns were also modeled using a royalty structure. The motive behind this royalty structure is the fact that the Dahl-Wilson model only looks at changes in value, not in revenue. To solve this problem, a model was created to find the NPV of the royalty returns. Wheat seed that is developed in North Dakota by a public institution can receive a $0.45 per acre royalty. Wheat seed can be reused for 3 years before the genetics become compromised; about 30% of planted acres are new seed. Private companies can charge various prices and can insist on no seed reuse. These results were implemented in the model by finding the NPV of returns that the decision maker would receive.

Acres planted were solved by looking at the minimum, maximum, and mean of spring wheat acres planted in North Dakota, Montana, South Dakota, and Minnesota from 2005 to a predicted 2017 to form an @RiskTriangle distribution. The market share was determined by looking at the varieties of spring wheat introduced into North Dakota and taking the minimum, maximum, and mean of their adoption cycles to form an @RiskTriangle distribution.

Model Details

The model used is an extension of (Guthrie, 2009), who developed a real-options model for an R&D program that contains more than one stage to be completed. The development of a new variety is identified as a growth option because of the development cycle's characteristics which are represented from F1-F11. The variety development of germplasm is considered to be a compound option because the initiation of one project phase depends on the successful completion of the preceding phase. An extension of Dahl and Wilson, an unpublished and forthcoming model is also used to value the marketable variety. The model is applied to wheat germplasm.

The first step in the option model is to map all the option derivatives on an option tree. During the second step, calculations are done to solve the inner nodes of the option tree through backward induction. In the third step, single-period probabilities are converted to risk-neutral probabilities in order to allow risk-neutral valuation. During the last step of the process, backward induction is repeated, this time using risk-neutral probabilities.

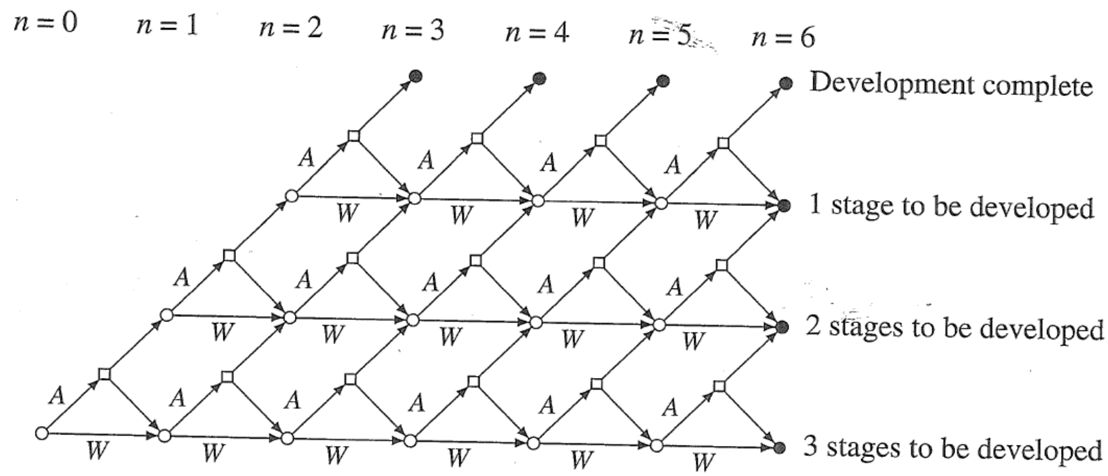

Figure 4.2. Compound Binomial Option Tree (Guthrie, 2009)

When using the compound binomial option tree model, there are only two outcomes to consider: continuing or waiting. These outcomes are shown in Figure 4.2 If the phase is considered to be successful, development will advance to the following phase. If the phase is deemed to be a failure, then the growth option is not exercised and the option expires. The option is only worth the salvage value. Figure 4.3 summarizes the option tree for wheat germplasm. The lower-level timelines reflect the phase and its base-case completion time. Each phase takes six months to one year to complete. Above the time component, along the options map, is the expect cost for each development phase.

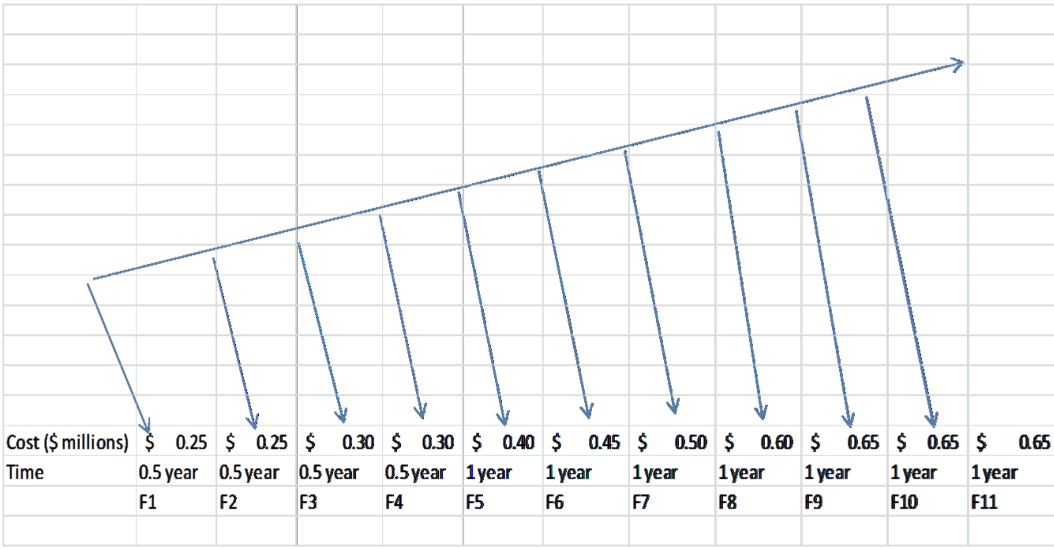

Figure 4.3. Options Map

The values of the inner nodes (not shown in Figure 4.3) are calculated by working backwards through the options tree. The most outer-node is the present value of cash flows from the time of commercialization to the end of the patent protection for the given germplasm.

The present value of the cash flow is determined as follows:

PV = (R * PA * A – RC) * $(1/1+\text{WACC})^t$,

where

R =Revenue received for the use germplasm
PA =Planted acres for the wheat
A =Adoption rate of the new germplasm
RC =Residual costs
T =Time
WACC =Weighted average cost of capital

Following the development of the cash flow’s present value, the cash flows are weighted at the end of every phase by its respective success and failure probabilities, and then the result is discounted by the duration of the phase, using an assumed weighted average cost of capital of 4%. This process continues until all the values along the inner nodes of the option tree have an assigned solution.

The single-period probabilities are then converted into risk-neutral probabilities. Risk-neutral probabilities are used in option pricing to use the risk-free interest rate as opposed to identifying the risk-adjusted discount rate. Jägle said that risk-neutral probabilities are the discrete-time equivalent to the method used in a continuous time option pricing of creating a risk-neutral "hedge" portfolio. When utilizing a risk-neutral portfolio, positions for the option and the underlying asset are combined, so the portfolio's value is the same as the underlying asset. Therefore, the value of the portfolio is not affected by the risk of price changes, and then, the risk-free interest rate can be used for discounting the portfolio's value to present (Jägle, 1999).

The risk neural probabilities for any node are solved as follows:

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

where:

P= Risk-neutral probability
R=Risk-free interest rate
T= Time in the phase of development
S=Current project value of project
S_+=Present cash-flow value at the end of a phase, in the case of upward movement
S_-=Present cash-flow value at the end of a phase, in the case of downward movement.

As with the first step, backward induction is used to calculate the option values for the outer nodes, but this time the risk neutral probabilities are used for the calculation. In order for the firm to exercise the growth option, the value must be greater than zero. In this case, as uncertainty is resolved, the option values increase. As the firm experiences more success, market knowledge increases, thus adding more "learning" value.

To help determine the upward and downward movements, the volatility of the returns needs to be found. This is determined by using the following formula (Amram, & Kulatilaka, 1999):

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(r_i - \bar{r})^2}{N-1}},$$

where:

$\bar{r}$ =Mean return
r_i = Return at period i

This volatility number is then used to determine the value of upward or downward NPV movement by taking the exponential value of the volatility results. The "up" and "down" numbers are used in the model to determine the option's value after an upward or downward movement.

Types of Options

This thesis models two options, "continue" or "wait" using the stochastic binomial-compound option model. When managers want to continue to the next stage and to make further investment, they will select the "continue" growth option. This selection would be the case if the option was in-the-money. If managers choose to wait, they would not make any further investment for the next stage. The option to "wait" for any stage is valued the same as the option to "continue" the previous stage with an additional time frame added to it without investment for a subsequent stage. Thus, the simplest binomial option tree would involve the option to "continue" and the option to "wait" on the project.

With the use of options, management can better compare and analyze the possible scenarios. These scenarios indicate that the variation in the option value for traits at different development stages had the management choose to "continue" or "wait". As an example, if management perceives that the difference in the option values for "continue" and "wait" is worth enough considering the current political and social environment, then the option to "wait" is a rational choice. The real-option methodology captures the risks associated with each development stage and takes into account the different choices available for managers at the end of each stage. The discounted cash-flow methodology fails to consider the possibility that management may choose to "wait" at the end of any stage. This result means that 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 to continue at a later time, the germplasm is at the same stage as previously, but in terms of time, the germplasm has elapsed to the next stage. For simplicity's sake, if the management chooses to wait, then the wait time is equal to the next development stage had the managers chosen to continue. This process helps draw out possible pathways that management can follow by making different choices at the end of each stage on a parallel basis. If management decides to "wait," a new option tree starts and progresses as a simple binomial option model. The new tree only evaluates option values for "continue" and "wait". Comparisons can then be made by looking at the option values at the nodes of possible pathways.

Management's choices affect the NPV. A constant rate of discounting the future cash flow is not appropriate and representative of the actual possible choices that are available to management. The germplasm's option value, as calculated in this thesis, at each development stage captures the risk of the germplasm moving to the next stage and the gain that particular breed is expected to provide for the end user. This value is because the option depends on the probability of succeeding, the time taken for the stage, the investment made in the stage, the adoption rate, and technology fees.

Data Sources and Distributions

Data were collected for the potential market size for each variety of wheat. Variety release data were obtained Mergoum et al. (2006, 2008). Glenn was released in 2006. Faller was released in 2007. Quality information was taken from(Ransom et al. (2005). The number of planted acres was taken from United State Department of Agriculture National Agricultural Statistical Service (USDA-NASS (2012)). A seasonal average was determined by the prices received from Hard Red Spring Wheat farmers and was from USDA-NASS (2012). Seasonal averages were also derived for protein premiums from the Minneapolis Grain Exchange (MGEX). Extraction and absorption premiums were adapted and estimated from Dahl et al. (2004).

Wheat revenue is determined by looking at the additional revenue from increased yield and protein as well as DON resistance. Yield values are found by taking the price times the yield advantage. The price is found using a lognormal distribution that looks at previous prices and their standard deviations. The yield advantage is bushels per acre advantages times the number of planted acres. Protein values are found by taking the price times the protein advantage. The protein advantage is bushels per acre advantages times the number of planted acres. DON resistance values are found by taking the yield, times planted acres, times the DON discount.

The life cycle behavior of the wheat variety was taken from Dahl, Wilson, and Wilson (1999), where market penetration was fairly slow in early years, rose rapidly, reached a peak, and slowly declines thereafter. For the sake of this thesis, the peaks were reached about 3-4 years after they were released.

Data for the development process were obtained from (Van Ginkel et al., 1998), (Li et al., 2013), and North Dakota State University. The dare are shown Table 4.1. Data included the time and cost for each development stage. Data included costs and time ensued during the breeding method.

Table 4.1. Germplasm Time and Costs

Generation	Time Year	Cost $(millions)
F1	0.5	0.25
F2	0.5	0.25
F3	0.5	0.30
F4	0.5	0.30
F5	1	0.40
F6	1	0.45
F7	1	0.50
F8	1	0.60
F9	1	0.65
F10	1	0.65
F11	1	0.64
Total	8	5.00

As with the element of time, the firm's ability to effectively manage cost dramatically increases the value of the germplasm's value. The investments that a firm makes at each stage of breeding are an estimate taken from the North Dakota State University's Plant Sciences and Agribusiness and Applied Economics departments. To our knowledge, these data are the most up-to-date interpretation of the cost for germplasm development. Estimates, rather than actual data, had to be used due to the accounting system not allowing for more detailed cost desegregation. A sensitivity analysis was conducted to measure the costs' effect on NPV.

Base Case

The base case presented is a likely scenario which sets the mean parameters for later sensitivity analysis. This base case model contains numerous random variables that determine the option's growth value. The revenue side of this option comes from the targeted germplasm development strategy and includes the yield advantage, protein advantage, and DON resistance.

The base case variables for the time it takes to complete development each stage are also included. Because of the growing seasons, each stage takes 1 year to complete. The use of compound growth options means that F1 has to be completed before F2 can get started, etc.

Assumptions include a risk-adjusted growth factor of 0.98. The risk-adjusted growth factor is calculated by subtracting the capital asset pricing model (CAPM) risk premium from the expected growth factor of the stated variable.

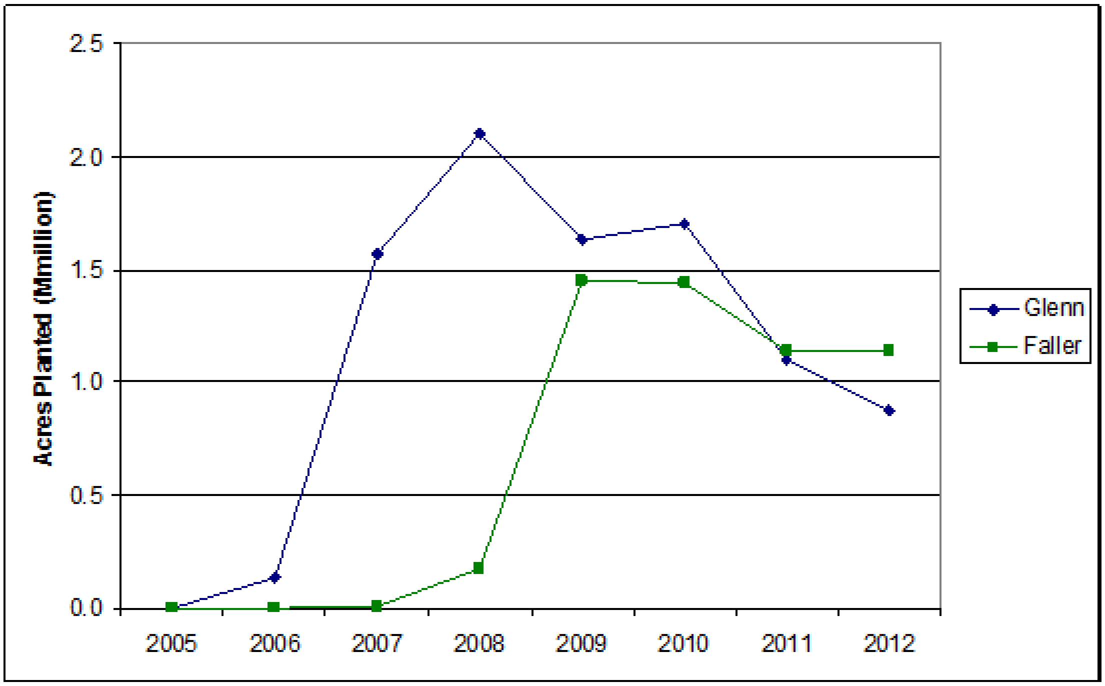

Figure 4.4. Acres Planted to Glenn and Faller in North Dakota, Minnesota, Montana, and South Dakota, 2005 to 2012

Another assumption was that 5.5 million acres were planted in the region (Minnesota, North Dakota, South Dakota, and Montana). The planted acres were assumed to be equal to the variety shares multiplied by the total acres. These acres are shown in Figure 4.4. Values for the market share were then fit to a curve which is shown in Figure 4.5.

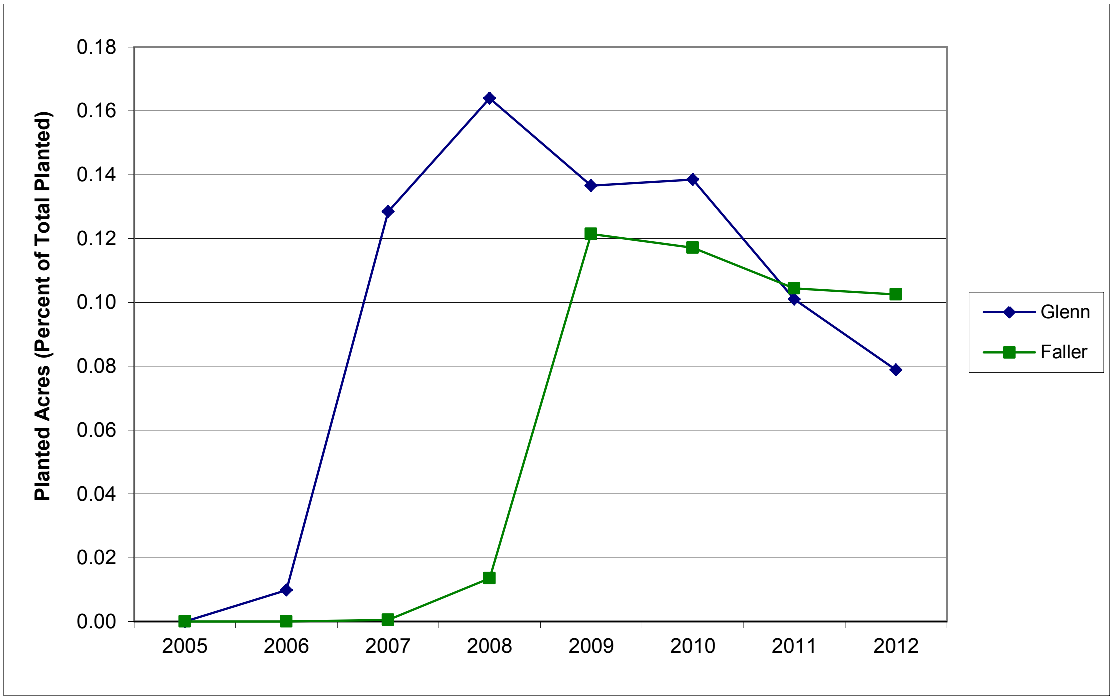

Figure 4.5. Percent Variety Adoption for Glenn and Faller in North Dakota, Minnesota, Montana and South Dakota, from 2005-2012

Simulation Procedure

The analytical model is a mathematical relationship used, for given values of certain inputs, to provide solutions to desired outputs (Winston, 2001). Additionally, in situations where there is risk present, the analytical solutions become more laborious and provide useful information for the decision maker. This relationship means that a simulation model is useful when no tractable analytical model exists. A simulation model imitates a live situation while allowing the use of random variables when discrete variables are unknown or inconsistent with certain parameters (Winston, 2001). The simulation is performed on critical variables to determine their effect on the model outcome or how sensitive the outcome is due to a given variable. The simulation provides decision makers with key information when deciding how to adapt to a changing environment.

@Risk used 10,000 simulations. Probability-distribution functions representing uncertainty are used to define the effect of random variables and are entered in an Excel spreadsheet instead of using a formula or number. One thousand iterations are performed successively until distributions are filled, and simulated results represent an accurate portrayal of a live simulation. These simulations are developed in Excel. The most likely event is simulated to find the base case.

Sensitivities

The random effects of costs, yield price and protein premiums, and DON resistance are reduced to examine the base case. To see how the variables affect the option's value, sensitivities are performed on the base case. Sensitivities are performed for Glenn and Faller wheat.

Discount Rate

The discount rate is often unknown for universitities and is generally an estimate. For the base case of this thesis, a rate of 4% was used. This rate was, once again, an estimate and did effect the breeding program's costs. Because of the differences for private and public reaseach facilities and their discount rates, the model was run again with a discount rate of 10%.

Cost

The development cost for a new variety of wheat is uncertain. Neither the wheat breeders nor the economists know a number for certain. This number is dependent on quality, disease, and genomic testing, in addition to overhead costs. In the case of this thesis, a triangle distribution is used.

Wheat Price

An increase in Hard Red Spring Wheat prices will increase the value of the variety if the yield also increases. Alternatively, the increased yield will not be as valuable if the prices stay the same or decrease. Yields were reported for eastern and western North Dakota. Yields for Montana and South Dakota were assumed to be similar to western, North Dakota and yield for Minnesota was assumed to be similar to eastern North Dakota.

Protein Premiums

Protein premiums have become extremely volatile during the past decade and will likely continue fluctuate in future years. This volatility will have an important impact on variety valuations. Along with the impact on variety valuations, the fluctuation will also impact the relative values of different varieties. The quality attributes were reported for the state of North Dakota and were assumed to be equal for the region.

Royalty Fees

Wheat seed that is developed in North Dakota by a public institution can receive $0.45 per acre royalty. Wheat seed can be reused for 3 years before the genetics become compromised. The result is that about 30% of planted acres are new seed. Private companies can charge various prices and can insist on no seed reuse. Therefore, three sensitivities were conducted utilizing both 30% seed use and 100% seed use along with a $0.45 per acre royalty and a $1.80 per acre royalty. The adoption rate used for this sensitivity is shown in Figure 4.6. The number of planted acres used for this sensitivity is shown in Figure 4.7.

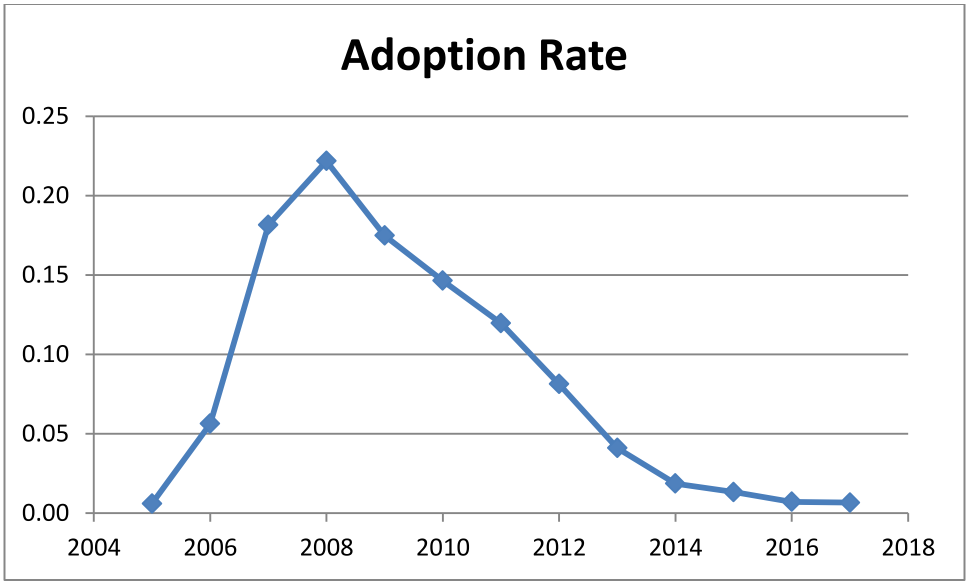

Figure 4.6. Adoption Rate

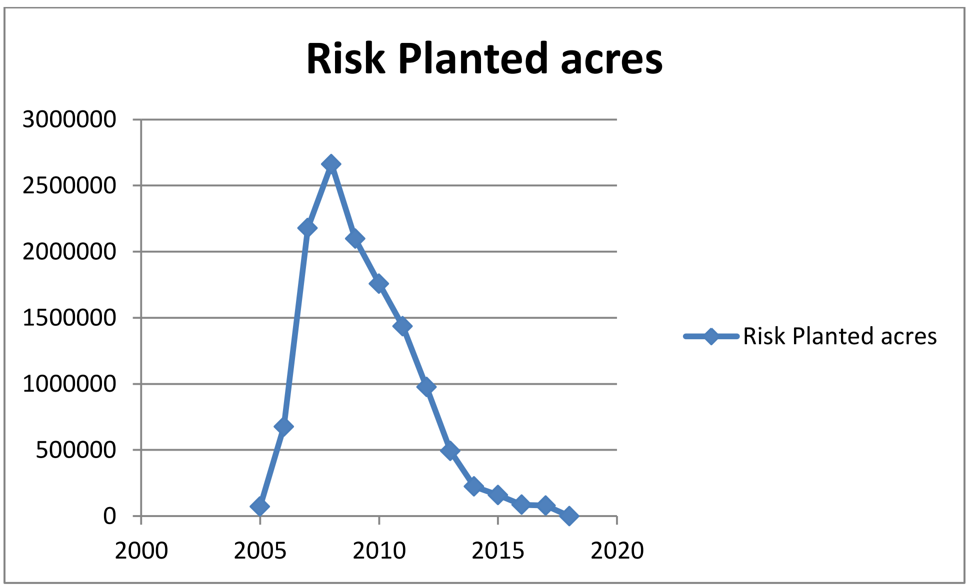

Figure 4.7. Planted Acres Using @Risk

5. RESULTS AND SENSITIVITES

Introduction

Not accounting for the adaptability and options in the germplasm development process has implications for research and development. These implications are not limited to the risk of investing in projects without considering the inherent value in acquiring new information. Errors involved with investment decision making drastically affect a firm's long-term profitability because of the time, investment, and risk associated with developing a new variety.

There are two essential analyses in this chapter. The first one determines the change in value using the Dahl-Wilson model. The second one is the returns received from royalty fees. The motive behind these analyses is the fact that Dahl-Wilson model only looks at changes in value, not in revenue. To solve this problem, a model was created to find the NPV of the royalty returns received by the decision maker.

The results of the base case along with sensitivities for the key-option value drivers are presented in this chapter. It is organized into four sections. The first section highlights results in a general context for all examined traits. Then, option values are analyzed for each type of germplasm and revenue profile. This analysis will allow decision makers to identify and rank worthy research-and-development opportunities. The following section provides sensitivities for the stochastic-option value drivers. Understanding the effect of key value drivers allows decision makers to better organize and control specific "events" in a timely investment process. Managerial implications are also identified for using option valuation in the research-and-development process. The final section is a Summary of the results.

Base-Case Results

The results are explained in the context of the entire analysis and then in greater detail. First, the net present value of Glenn and Faller is derived by taking changes in yield, protein, and DON into account.

Results: Glenn

The value from yield was negative 100% of the time. This result was expected because Glenn was not bred to increase yields. The value from protein was positive 100% of the time. This result was also expected as Glenn has increased protein absorption. Alternatively, it has the second highest standard deviation, which could cause concern. The value from DON resistance was greater than zero 100% of the time. On average, it added $2.6 million to the value.

The NPV values of Glenn were then analyzed using a real options model. Glenn was not profitable to continue at the F1 stage until after 11 periods of upward movement. This potential means that Glenn was not a profitable variety to breed. This result is shown in Table 5.3.

Table 5.1. Glenn Results

Glenn Results (in millions)				
	MIN	MAX	Mean	Standard Deviation
NPV	-37	172	1.1	20
Yield	-64	-43	-52	2.7
Protein	15	218	50	19
DON	0	102	2.6	5.9

Table 5.2 displays the binomial market value for the first eight years, taking into account an up or down move. Time 0,0 is f the germplasm's value if it were available today. Moving to the right shows an increase in value. Moving down is a decrease in value. The NPV of the variety is in-the-money 44.2% of the time. This result is taken from Figure 5.1. Alternatively, when using real options, the variety in the F1 stage does not become positive until year 12. This result is shown in Table 5.3. A breeder would not choose to continue breeding until year 15. This result is shown in Table 5.4.

Table 5.2. Glenn: Binomial Options Tree

X(i,n)	0	1	2	3	4	5	6	7	8
0	1.09	1.31	1.58	1.91	2.30	2.77	3.34	4.03	4.86
1		0.90	1.09	1.31	1.58	1.91	2.30	2.77	3.34
2			0.75	0.90	1.09	1.31	1.58	1.91	2.30
3				0.62	0.75	0.90	1.09	1.31	1.58
4					0.52	0.62	0.75	0.90	1.09
5						0.43	0.52	0.62	0.75
6							0.36	0.43	0.52
7								0.29	0.36
8									0.24

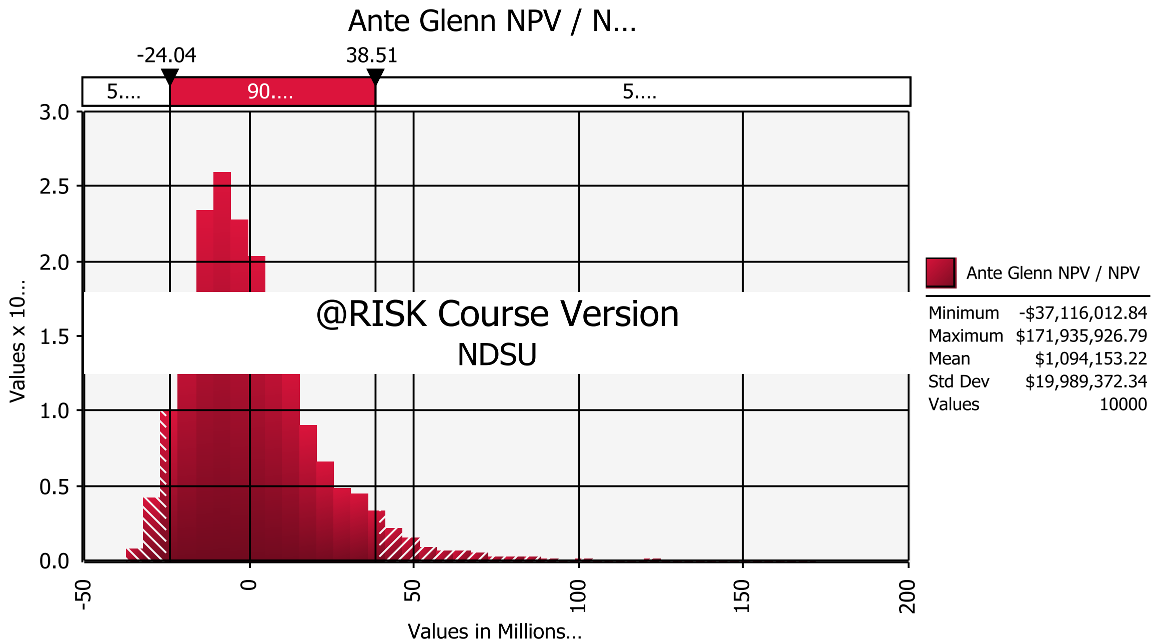

Figure 5.1. Ante Glenn NPV

Table 5.3. Glenn Value at Time F1

$F_1(i,n)$	0	1	2	3	4	5	6	7	8	9	10	11	12
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
1		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3				0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5						0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6							0.00	0.00	0.00	0.00	0.00	0.00	0.00
7								0.00	0.00	0.00	0.00	0.00	0.00
8									0.00	0.00	0.00	0.00	0.00
9										0.00	0.00	0.00	0.00
10											0.00	0.00	0.00
11												0.00	0.00
12													0.00

Table 5.4. Glenn Attempt/Do Not Attempt at F1

Policy(i,n)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Continue
1		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2			-	-	-	-	-	-	-	-	-	-	-	-	-	-
3				-	-	-	-	-	-	-	-	-	-	-	-	-
4					-	-	-	-	-	-	-	-	-	-	-	-
5						-	-	-	-	-	-	-	-	-	-	-
6							-	-	-	-	-	-	-	-	-	-
7								-	-	-	-	-	-	-	-	-
8									-	-	-	-	-	-	-	-
9										-	-	-	-	-	-	-

Glenn: Ex-Post

An ex-post analysis was conducted using actual data when available. The base case used predicted numbers, not actual numbers. The ex-post performance of Glenn was improved relative to commercial incumbents and also included additional variables including flour extraction and flour absorption. This result is shown in Table 5.5. There was also a sharp spike in price levels and protein premiums during 2010 and 2011. The results showed that the value of Glenn is about $136 million, which was substantially higher than previously predicted. An ex-post binomial option tree is shown in Table 5.6. Going to the right is an increasing NPV. Going down is decreasing NPV. Table 5.7 is the ex-post option value at the F1 stage.

Table 5.5. Ex-Post Glenn Results

Glenn Results (in millions)		
	Ex Ante	Ex Post
NPV	1.1	136
Yield	-52	-80
Protein	50	227
DON	2.6	0
Flour Extraction	-	-20
Flour Absorption	-	8.8

Table 5.6. Ex-Post Glenn Binomial Option Tree

X(i,n)	0	1	2	3	4	5	6	7	8
0	136.14	164.10	197.82	238.45	287.44	346.49	417.68	503.48	606.92
1		112.93	136.14	164.10	197.82	238.45	287.44	346.49	417.68
2			93.69	112.93	136.14	164.10	197.82	238.45	287.44
3				77.72	93.69	112.93	136.14	164.10	197.82
4					64.47	77.72	93.69	112.93	136.14
5						53.49	64.47	77.72	93.69
6							44.37	53.49	64.47
7								36.81	44.37
8									30.54

Table 5.7. Ex-Post Glenn at F1

F_1(i,n)	0	1	2	3	4	5	6	7	8
0	53.90	66.17	80.93	98.69	119.98	145.44	175.68	211.25	252.48
1		43.37	53.47	65.61	80.20	97.64	118.40	142.86	171.26
2			34.42	42.67	52.59	64.47	78.64	95.37	114.87
3				26.71	33.36	41.35	50.90	62.22	75.47
4					19.95	25.20	31.48	38.97	47.79
5						13.98	17.96	22.72	28.36
6							8.78	11.61	15.01
7								4.52	6.33
8									1.51

Results: Faller

The value from yield was positive 100% of the time. This result was expected because Faller was bred to increase yields. The value from protein was negative 100% of the time. This result was also expected as Faller was not bred to increase protein. The value from DON resistance was greater than zero 95% of the time. On average, it added $1.1 million to the value, which was relatively small considering that the total NPV was nearly $218 million. These results are shown in Table 5.8. The NPV distribution of Faller is shown in Figure 5.2.

Table 5.8. Faller Results

Faller Results (in millions)				
	MIN	MAX	Mean	Standard Deviation
NPV	18	268	218	18
Yield	219	285	251	9.7
Protein	-219	-8	-34	14
DON	-8.9	41	1.1	2.7

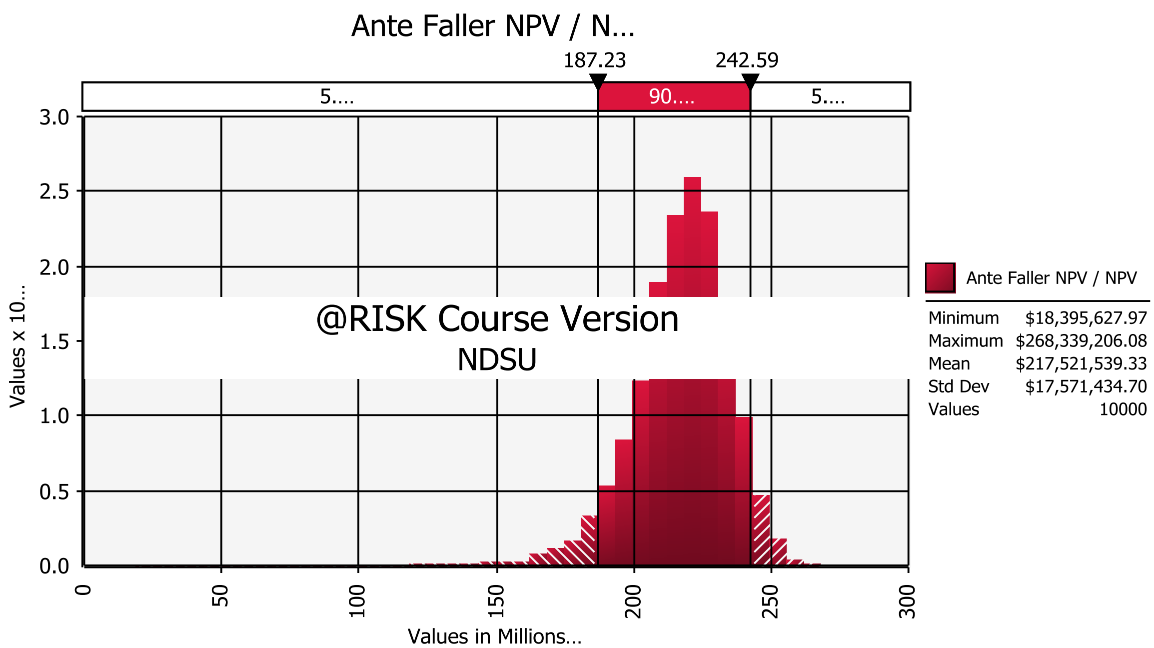

Figure 5.2. Ante Faller NPV

On average, among the chosen traits, the increased yield is most valuable. Table 5.9 displays the binomial market value for the first 10 years. Time 0,0 is the germplasm's value if it were available today. Moving right is an increase in NPV. Moving down is a decrease in the NPV. The NPV of the variety was in-the-money 100% of the time. This result is displayed in Figure 5.2. Using real options and beginning at generation F1, the decision maker would always chose to continue. The value of the option is always positive.

Table 5.9. Faller Binomial Option Tree

X(i,n)	0	1	2	3	4	5	6	7	8
0	217.5	224.6	231.9	239.5	247.4	255.5	263.8	272.4	281.3
1		210.63	217.52	224.6	231.98	239.57	247.41	255.50	263.85
2			203.96	210.63	217.52	224.64	231.98	239.57	247.41
3				197.50	203.96	210.63	217.52	224.64	231.98
4					191.25	197.50	203.96	210.63	217.52
5						185.19	191.25	197.50	203.96
6							179.33	185.19	191.25
7								173.65	179.33
8									168.1

Faller: Ex-Post

An ex-post analysis was conducted using actual data when they were available. The ex post performance of Faller was inferior relative to commercial incumbents. Because of the sharp increase of protein premiums and Faller's lack of high protein, the ex-post value was a loss of $151 million. This result makes Faller always unprofitable to develop. A comparison of Faller ex-ante and ex-post is shown in Table 5.10. Table 5.11 shows the Ex Post binomial option tree. It is clear that the value is always negative. Table 5.12 shows the value of Faller at F1. The option value is always 0, and we would not chose to develop or to "continue."

Table 5.10. Ex-Post Faller Results

Faller Results (in millions)		
	Ex Ante	Ex Post
NPV	218	-151
Yield	251	84
Protein	-34	-241
DON	1.1	0
Flour Extraction	-	33
Flour Absorption	-	-27

Table 5.11. Ex-Post Faller Binomial Option Tree

X(i,n)	0	1	2	3	4	5	6	7	8
0	-151.2	-156.1	-161.2	-166.5	-172.0	-177.6	-183.4	-189.4	-195.6
1		-146.4	-151.2	-156.1	-161.2	-166.5	-172.0	-177.6	-183.4
2			-141.8	-146.4	-151.2	-156.1	-161.2	-166.5	-172.0
3				-137.3	-141.8	-146.4	-151.2	-156.1	-161.2
4					-132.9	-137.3	-141.8	-146.4	-151.2
5						-128.7	-132.9	-137.3	-141.8
6							-124.6	-128.7	-132.9
7								-120.7	-124.6
8									-116.9

Table 5.12. Ex-Post Faller at F1

F_1(i,n)	0	1	2	3	4	5	6	7	8
0	0	0	0	0	0	0	0	0	0
1		0	0	0	0	0	0	0	0
2			0	0	0	0	0	0	0
3				0	0	0	0	0	0
4					0	0	0	0	0
5						0	0	0	0
6							0	0	0
7								0	0
8									0

Sensitivites: Discount Rate

The discount rate, sometimes referred to as the opportunty cost of capital, is often unknown for universitities and is generally an estimate. For this thesis, a rate of 4% was used. Because of the differences with private and public research facilities and their discount rates, the model was run again with a discount rate of 10%. Results are shown in Table 5.13 for Glenn and in Table 5.14 for Faller. With the increasd discount rate, the NPV of both Glenn and Faller decreased. It should also be noted that an increase in the discount rate decreased the standard devation in both cases.

Table 5.13. Glenn NPV Results

Glenn Results (in millions)				
	MIN	MAX	Mean	St. dev.
NPV at 4%	-37	172	1.1	20
NPV at 10%	-29	139	0.8	15

Table 5.14. Faller NPV Results

Faller Results (in millions)				
	MIN	MAX	Mean	St. dev.
NPV at 4%	18	268	218	18
NPV at 10%	-5	181	146	12

Sensitivities: Breeding Costs

In the base case, breeding costs were estimated at $5 million for the total program. These costs were estimates. To evaluate the impact of these costs, sensitivities were conducted. When costs were lowered the Faller breeding strategy was not affected. Lower costs did, however, make it more profitable to continue breeding Glenn. A breeder would choose to attempt breeding at year 12, after 11 continuous years of increasing NPV, instead of at year 15. This is shown in Table 5.15.

Table 5.15. Glenn at F1 with Lowered Breeding Costs

Policy(i,n)	0	1	2	3	4	5	6	7	8	9	10	11	12
0	-	-	-	-	-	-	-	-	-	-	-	-	Continue
1		-	-	-	-	-	-	-	-	-	-	-	-
2			-	-	-	-	-	-	-	-	-	-	-
3				-	-	-	-	-	-	-	-	-	-
4					-	-	-	-	-	-	-	-	-
5						-	-	-	-	-	-	-	-
6							-	-	-	-	-	-	-

Alternatively, if one raises the breeding costs to $10 million, it is continually unprofitable to attempt breeding the Glenn variety at any time. Faller still continues to be profitable at time zero to continue breeding. This result is shown in Table 5.16.

Table 5.16. Faller at F1 with Increased Breeding Costs

Policy(i,n)	0	1	2	3	4	5
0	Continue	Continue	Continue	Continue	Continue	Continue
1		Continue	Continue	Continue	Continue	Continue
2			Continue	Continue	Continue	Continue
3				Continue	Continue	Continue
4					Continue	Continue
5						Continue

Sensitivities: Wheat Prices

A sensitivity analysis was conducted with both the Glenn and Faller varieties by changing the wheat prices by $0.15. The results did not change either standard deviation. Table 5.17 shows that as prices increased, Glenn's NPV decreased as did its yield value. This result can be explained by the fact that Glenn did not have highly increasing yields. Table 5.18 shows that, as prices increased, so did the NPV and the yield value for Faller. This result can be explained by the fact that Faller had increased yields and, thus, would reap the benefits of increased prices. As the NPV decreases, the option value decreases as well. If the NPV increases, the option value increases, and this increase makes the variety more profitable to produce.

Table 5.17. Glenn Price Sensitivity

Glenn Results (in millions)				
	MIN	MAX	Mean	Standard deviation
Prices at $3.20				
NPV	-35	174	3.4	20
Yield	-61	-40	-49	2.7
Prices at $3.35				
NPV	-37	172	1.1	20
Yield	-64	-43	-52	2.7
Prices at $3.50				
NPV	-39	170	-1.1	20
Yield	-66	-45	-54	2.7

Table 5.18. Faller Price Sensitivity

Faller Results (in millions)				
	MIN	MAX	Mean	Standard deviation
Prices at $3.50				
NPV	-4.4	246	195	18
Yield	199	263	228	9.7
Prices at $3.85				
NPV	18	268	218	18
Yield	219	285	251	9.7
Prices at $4.00				
NPV	28	278	227	18
Yield	228	295	260	9.7

Sensitivities: Protein Premium

The sensitivity results varied from Glenn to Faller. First, it should be noted that Glenn had a positive protein change/improvement relative to incumbent varieties (48%)

while Faller had a negative protein change/improvement relative to incumbent varieties (51%) in the base case. By increasing the protein advantage in Glenn and Faller, the NPV increased, too. This change also increased the standard deviation. The results can be seen in Table 5.19 for Glenn and in Table 5.20 for Faller.

Table 5.19. Glenn Protein Results

Glenn Results (in millions)				
	MIN	MAX	Mean	Standard Deviation
Protein at 38%				
NPV	-42	127	-9	16
Protein	12	173	40	15
Protein at 48%				
NPV	-37	172	1.1	20
Protein	15	218	50	19
Protein at 58%				
NPV	-34	218	12	24
Protein	18	265	61	23

Table 5.20. Faller Protein Results

Faller Results (in millions)				
	MIN	MAX	Mean	Standard Deviation
Protein at -61%				
NPV	-25	265	211	20
Protein	-263	-10	-41	17
Protein at -51%				
NPV	18	268	218	18
Protein	-219	-8	-34	14
Protein at -41%				
NPV	61	217	224	15
Protein	-177	-6	28	12

Royalty Results

Wheat seed that is developed in North Dakota by a public institution can receive a $0.45 per acre royalty. Wheat seed can be reused for 3 years before the genetics become compromised; about 30% of planted acres are new seed. Private companies can charge various prices and can insist on no seed reuse. Therefore, three sensitivities were conducted using both 30% seed use and 100% seed use along with $0.45 and $1.80 per acre royalties. The NPV results are shown in Table 5.21.

Table 5.21. Royalty Income

Royalty Income	
30% seed use at $0.45	$1,421,213
30% seed use at $1.80	$5,684,853
100% seed use at $1.80	$18,949,510

Figures 5.3-5.5 show the distributions for the different royalty results. Tables 5.22-5.24 show the binomial option trees for the different royalty results. Moving across illustrates years in the future and an increase in NPV. Moving downward is demonstrating a decreased NPV. The F1 option values are shown in Tables 5.25-5.27. Because of the low rate of returns and small standard deviation, a decision maker would never choose to continue at the F1 stage with 30% seed use. However, breeding should be continued with 100% seed use. This result is demonstrated in Table 5.28.

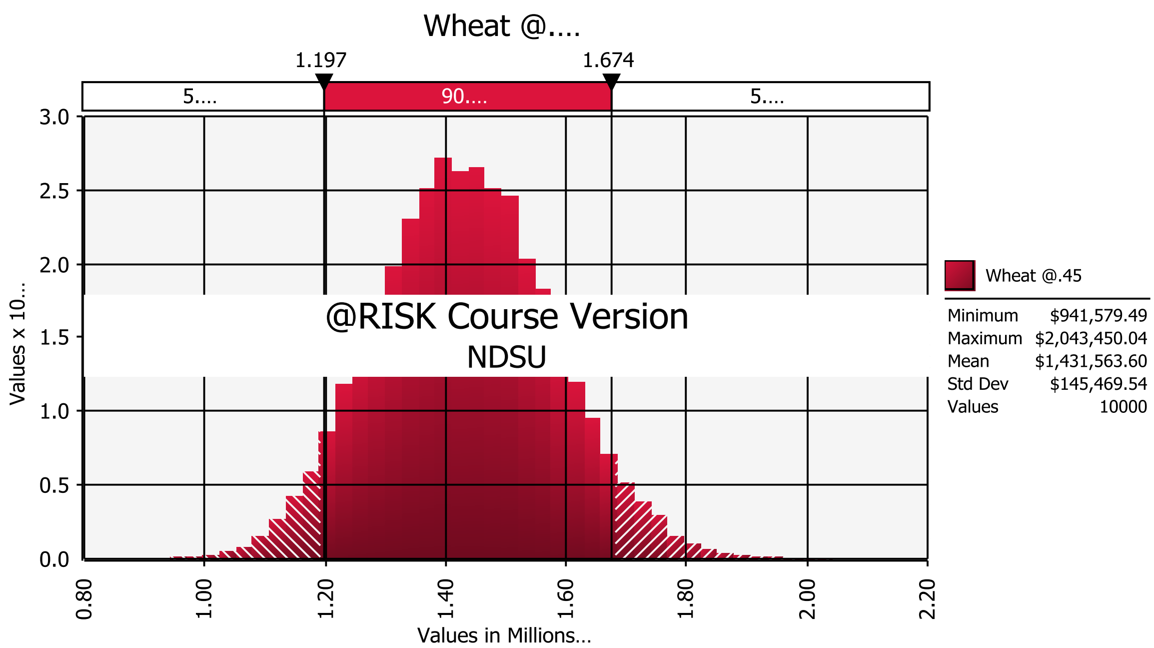

Figure 5.3. Wheat Distribution a with $0.45 Royalty Fee

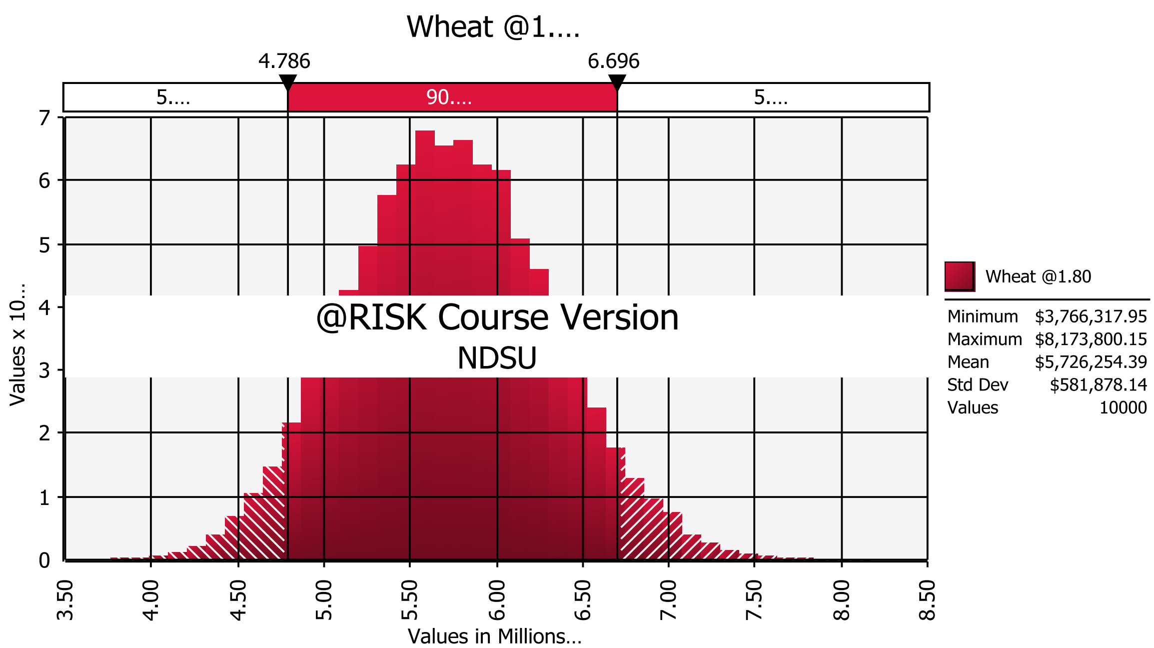

Figure 5.4. Wheat with a 30% Use Rate and a $1.80 Royalty Fee

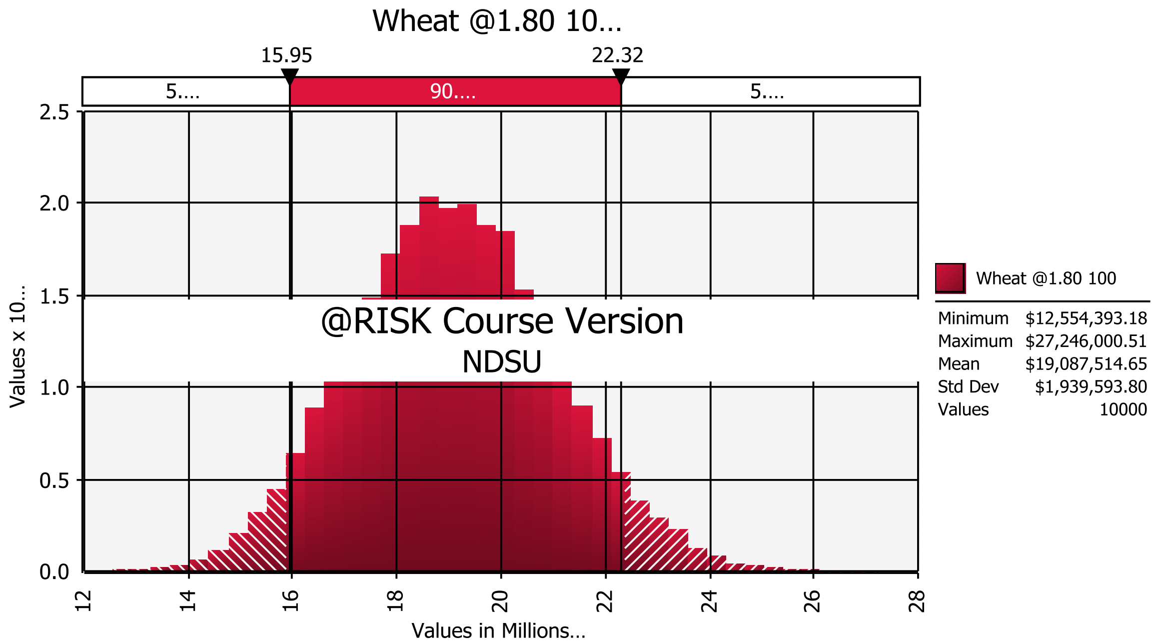

Figure 5.5. Wheat with a 100% Use Rate and a $1.80 Royalty Fee

Table 5.22. Binomial Option Tree with 30% Seed Use at $0.45

X(i,n)	0	1	2	3	4	5	6	7	8
0	1.42	1.48	1.54	1.60	1.66	1.72	1.79	1.86	1.94
1		1.37	1.42	1.48	1.54	1.60	1.66	1.72	1.79
2			1.32	1.37	1.42	1.48	1.54	1.60	1.66
3				1.27	1.32	1.37	1.42	1.48	1.54
4					1.22	1.27	1.32	1.37	1.42
5						1.17	1.22	1.27	1.32
6							1.13	1.17	1.22
7								1.08	1.13
8									1.04

Table 5.23. Binomial Option Tree with 30% Seed Use at $1.80

X(i,n)	0	1	2	3	4	5	6	7	8
0	5.69	5.91	6.14	6.38	6.63	6.90	7.17	7.45	7.74
1		5.47	5.69	5.91	6.14	6.38	6.63	6.90	7.17
2			5.26	5.47	5.69	5.91	6.14	6.38	6.63
3				5.06	5.26	5.47	5.69	5.91	6.14
4					4.87	5.06	5.26	5.47	5.69
5						4.69	4.87	5.06	5.26
6							4.51	4.69	4.87
7								4.34	4.51
8									4.17

Table 5.24. Binomial Option Tree with 100% Seed Use at $1.80

X(i,n)	0	1	2	3	4	5	6	7	8
0	18.95	19.70	20.47	21.28	22.12	22.99	23.89	24.83	25.81
1		18.23	18.95	19.70	20.47	21.28	22.12	22.99	23.89
2			17.54	18.23	18.95	19.70	20.47	21.28	22.12
3				16.88	17.54	18.23	18.95	19.70	20.47
4					16.24	16.88	17.54	18.23	18.95
5						15.62	16.24	16.88	17.54
6							15.03	15.62	16.24
7								14.46	15.03
8									13.91

Table 5.25. F1 with 30% Seed Use at $0.45

F_1(i,n)	0	1	2	3	4	5	6	7	8
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2			0.00	0.00	0.00	0.00	0.00	0.00	0.00
3				0.00	0.00	0.00	0.00	0.00	0.00
4					0.00	0.00	0.00	0.00	0.00
5						0.00	0.00	0.00	0.00
6							0.00	0.00	0.00
7								0.00	0.00
8									0.00

Table 5.26. F1 with 30% Seed Use at $1.80

$F_1(i,n)$	0	1	2	3	4	5	6	7	8
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2			0.00	0.00	0.00	0.00	0.00	0.00	0.00
3				0.00	0.00	0.00	0.00	0.00	0.00
4					0.00	0.00	0.00	0.00	0.00
5						0.00	0.00	0.00	0.00
6							0.00	0.00	0.00
7								0.00	0.00
8									0.00

Table 5.27. F1 with 100% Seed Use at $1.80

$F_1(i,n)$	0	1	2	3	4	5	6	7	8
0	1.70	1.98	2.27	2.58	2.89	3.22	3.56	3.92	4.28
1		1.07	1.31	1.55	1.81	2.08	2.36	2.66	2.97
2			0.46	0.63	0.82	1.01	1.22	1.44	1.67
3				0.02	0.09	0.20	0.32	0.44	0.57
4					0.00	0.00	0.00	0.00	0.00
5						0.00	0.00	0.00	0.00
6							0.00	0.00	0.00
7								0.00	0.00
8									0.00

Table 5.28. F1 with 100% Seed Use at $1.80

Policy(i,n)	0	1	2	3	4	5
0	Continue	Continue	Continue	Continue	Continue	Continue
1		Continue	Continue	Continue	Continue	Continue
2			Continue	Continue	Continue	Continue
3				-	Continue	Continue
4					-	-
5						-

Sensitivity: Royalty Volatility

Previously, the volatility of the NPV was found by looking at the returns generated by the 10,000 @Risk simulations. For the case of royalties the number was 0.039. A sensitivity analysis was conducted by changing the volatility to 0.1, 0.2, and 0.3. The results for 0.1 volatility are shown in Tables 5.29-5.36. The results for a 0.2 volatility are shown in Tables 5.37-5.42. The results for a 0.3 volatility are shown in tables 5.43-5.48. A decision maker would still choose not to continue breeding at F1 with 30% seed use at \$0.45. However, the results do change with the increase to \$1.80. This result is shown in Table 5.32. There is also an increase in "continue" with 100% seed-use, which is shown in Table 5.33.

The results indicate that, as the volatility increases, there is a great chance that the decision maker should "continue." This result is because, as volatility increases, the upward values become larger. Alternately, the downward values also become smaller.

When comparing the \$0.45 royalty and the \$1.80 royalty, it is found that, when royalties are larger, the returns are also larger. Rarely is wheat profitable to produce at \$.045. It is still produced by public institutions because they are not only looking at returns, but also looking at increased value for the end user and the general public.

Table 5.29. Binomial Market Value with 30% Seed Use at $0.45 with .1 Volatility

X(i,n)	0	1	2	3	4	5	6	7	8
0	1.42	1.57	1.74	1.92	2.12	2.34	2.59	2.86	3.16
1		1.29	1.42	1.57	1.74	1.92	2.12	2.34	2.59
2			1.16	1.29	1.42	1.57	1.74	1.92	2.12
3				1.05	1.16	1.29	1.42	1.57	1.74
4					0.95	1.05	1.16	1.29	1.42
5						0.86	0.95	1.05	1.16
6							0.78	0.86	0.95
7								0.71	0.78
8									0.64

Table 5.30. Binomial Market Value with 30% Seed Use at $1.80 with .1 Volatility

X(i,n)	0	1	2	3	4	5	6	7	8
0	5.69	6.28	6.94	7.67	8.48	9.37	10.36	11.45	12.65
1		5.14	5.69	6.28	6.94	7.67	8.48	9.37	10.36
2			4.65	5.14	5.69	6.28	6.94	7.67	8.48
3				4.21	4.65	5.14	5.69	6.28	6.94
4					3.81	4.21	4.65	5.14	5.69
5						3.45	3.81	4.21	4.65
6							3.12	3.45	3.81
7								2.82	3.12
8									2.55

Table 5.31. Binomial Market Value with 100% Seed Use at $1.80 with .1 Volatility

X(i,n)	0	1	2	3	4	5	6	7	8
0	18.95	20.94	23.15	25.58	28.27	31.24	34.53	38.16	42.17
1		17.15	18.95	20.94	23.15	25.58	28.27	31.24	34.53
2			15.51	17.15	18.95	20.94	23.15	25.58	28.27
3				14.04	15.51	17.15	18.95	20.94	23.15
4					12.70	14.04	15.51	17.15	18.95
5						11.49	12.70	14.04	15.51
6							10.40	11.49	12.70
7								9.41	10.40
8									8.51

Table 5.32. F1 with 30% Seed Use at \$0.45 with .1 Volatility

$F_1(i,n)$	0	1	2	3	4	5	6	7	8
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2			0.00	0.00	0.00	0.00	0.00	0.00	0.00
3				0.00	0.00	0.00	0.00	0.00	0.00
4					0.00	0.00	0.00	0.00	0.00
5						0.00	0.00	0.00	0.00
6							0.00	0.00	0.00
7								0.00	0.00
8									0.00

Table 5.33. F1 with 30% Seed Use at \$1.80 with .1 Volatility

$F_1(i,n)$	0	1	2	3	4	5	6	7	8
0	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.12
1		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
2			0.00	0.00	0.00	0.00	0.00	0.00	0.00
3				0.00	0.00	0.00	0.00	0.00	0.00
4					0.00	0.00	0.00	0.00	0.00
5						0.00	0.00	0.00	0.00
6							0.00	0.00	0.00
7								0.00	0.00
8									0.00

Table 5.34. F1 with 100% Seed use at \$1.80 with .1 Volatility

$F_1(i,n)$	0	1	2	3	4	5	6	7	8
0	2.37	3.23	4.17	5.22	6.38	7.64	9.01	10.49	12.02
1		1.53	2.27	3.10	4.03	5.05	6.16	7.36	8.63
2			0.80	1.39	2.09	2.89	3.77	4.73	5.75
3				0.27	0.63	1.16	1.80	2.53	3.32
4					0.06	0.16	0.40	0.83	1.36
5						0.01	0.02	0.06	0.16
6							0.00	0.00	0.00
7								0.00	0.00
8									0.00

Table 5.35. F1 with 30% Seed Use at $1.80 with .1 Volatility

Policy(i,n)	0	1	2	3	4	5	6	7	8	9	10	11	12
0	-	-	-	-	-	-	-	-	-	Continue	Continue	Continue	Continue
1		-	-	-	-	-	-	-	-	-	-	Continue	Continue
2			-	-	-	-	-	-	-	-	-	-	-
3				-	-	-	-	-	-	-	-	-	-
4					-	-	-	-	-	-	-	-	-

Table 5.36. F1 with 100% Seed Use at $1.80 with .1 Volatility

Policy(i,n)	0	1	2	3	4	5	6
0	Continue	Continue	Continue	Continue	Continue	Continue	Continue
1		Continue	Continue	Continue	Continue	Continue	Continue
2			Continue	Continue	Continue	Continue	Continue
3				-	Continue	Continue	Continue
4					-	-	Continue
5						-	-
6							-

Table 5.37. Binomial Market Value with 30% Seed Use at $0.45 with .2 Volatility

X(i,n)	0	1	2	3	4	5	6	7	8
0	1.42	1.74	2.12	2.59	3.16	3.86	4.72	5.76	7.04
1		1.16	1.42	1.74	2.12	2.59	3.16	3.86	4.72
2			0.95	1.16	1.42	1.74	2.12	2.59	3.16
3				0.78	0.95	1.16	1.42	1.74	2.12
4					0.64	0.78	0.95	1.16	1.42
5						0.52	0.64	0.78	0.95
6							0.43	0.52	0.64
7								0.35	0.43
8									0.29

Table 5.38. F1 with 30% Seed Use at $0.45 with .2 Volatility

$F_1(i,n)$	0	1	2	3	4	5	6	7	8
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02
1		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2			0.00	0.00	0.00	0.00	0.00	0.00	0.00
3				0.00	0.00	0.00	0.00	0.00	0.00
4					0.00	0.00	0.00	0.00	0.00
5						0.00	0.00	0.00	0.00
6							0.00	0.00	0.00
7								0.00	0.00
8									0.00

Table 5.39. Binomial Market Value with 30% Seed Use at $1.80 with .2 Volatility

X(i,n)	0	1	2	3	4	5	6	7	8
0	5.69	6.94	8.48	10.36	12.65	15.45	18.87	23.05	28.16
1		4.65	5.69	6.94	8.48	10.36	12.65	15.45	18.87
2			3.81	4.65	5.69	6.94	8.48	10.36	12.65
3				3.12	3.81	4.65	5.69	6.94	8.48
4					2.55	3.12	3.81	4.65	5.69
5						2.09	2.55	3.12	3.81
6							1.71	2.09	2.55
7								1.40	1.71
8									1.15

Table 5.40 .F1 with 30% Seed Use at $1.80 with .2 Volatility

$F_1(i,n)$	0	1	2	3	4	5	6	7	8
0	0.04	0.09	0.18	0.36	0.70	1.34	2.50	4.15	6.19
1		0.02	0.03	0.07	0.14	0.30	0.60	1.21	2.35
2			0.00	0.01	0.02	0.05	0.10	0.22	0.48
3				0.00	0.00	0.00	0.01	0.02	0.06
4					0.00	0.00	0.00	0.00	0.00
5						0.00	0.00	0.00	0.00
6							0.00	0.00	0.00
7								0.00	0.00
8									0.00

Table 5.41. Binomial Market Value with 100% Seed Use at $1.80 with .2 Volatility

X(i,n)	0	1	2	3	4	5	6	7	8
0	18.95	23.15	28.27	34.53	42.17	51.51	62.92	76.85	93.86
1		15.51	18.95	23.15	28.27	34.53	42.17	51.51	62.92
2			12.70	15.51	18.95	23.15	28.27	34.53	42.17
3				10.40	12.70	15.51	18.95	23.15	28.27
4					8.51	10.40	12.70	15.51	18.95
5						6.97	8.51	10.40	12.70
6							5.71	6.97	8.51
7								4.67	5.71
8									3.83

Table 5.42. F1 with 100% Seed Use at $1.80 with .2 Volatility

F_1(i,n)	0	1	2	3	4	5	6	7	8
0	2.64	4.35	6.56	9.28	12.60	16.63	21.49	27.29	34.13
1		1.43	2.59	4.30	6.48	9.16	12.40	16.29	20.88
2			0.70	1.34	2.51	4.19	6.31	8.88	11.95
3				0.30	0.61	1.21	2.35	3.96	5.95
4					0.11	0.23	0.48	1.01	2.08
5						0.03	0.06	0.15	0.33
6							0.00	0.01	0.03
7								0.00	0.00
8									0.00

Table 5.43. Binomial Market Value with 30% Seed Use at $0.45 with .3 Volatility

X(i,n)	0	1	2	3	4	5	6	7	8
0	1.42	1.92	2.59	3.50	4.72	6.37	8.60	11.60	15.66
1		1.05	1.42	1.92	2.59	3.50	4.72	6.37	8.60
2			0.78	1.05	1.42	1.92	2.59	3.50	4.72
3				0.58	0.78	1.05	1.42	1.92	2.59
4					0.43	0.58	0.78	1.05	1.42
5						0.32	0.43	0.58	0.78
6							0.23	0.32	0.43
7								0.17	0.23
8									0.13

Table 5.44. F1 with 30% Seed use at $.45 with .3 Volatility

$F_1(i,n)$	0	1	2	3	4	5	6	7	8
0	0.00	0.01	0.02	0.04	0.08	0.18	0.38	0.80	1.66
1		0.00	0.00	0.00	0.01	0.02	0.05	0.12	0.27
2			0.00	0.00	0.00	0.00	0.00	0.01	0.03
3				0.00	0.00	0.00	0.00	0.00	0.00
4					0.00	0.00	0.00	0.00	0.00
5						0.00	0.00	0.00	0.00
6							0.00	0.00	0.00
7								0.00	0.00
8									0.00

Table 5.45. Binomial Market Value with 30% Seed use at $1.80 with .3 Volatility

X(i,n)	0	1	2	3	4	5	6	7	8
0	5.69	7.67	10.36	13.98	18.87	25.48	34.39	46.42	62.67
1		4.21	5.69	7.67	10.36	13.98	18.87	25.48	34.39
2			3.12	4.21	5.69	7.67	10.36	13.98	18.87
3				2.31	3.12	4.21	5.69	7.67	10.36
4					1.71	2.31	3.12	4.21	5.69
5						1.27	1.71	2.31	3.12
6							0.94	1.27	1.71
7								0.70	0.94
8									0.52

Table 5.46. F1 with 30% Seed Use at $1.80 with .3 Volatility

$F_1(i,n)$	0	1	2	3	4	5	6	7	8
0	0.22	0.44	0.85	1.62	3.02	5.53	9.21	14.24	20.90
1		0.09	0.19	0.38	0.76	1.50	2.90	5.37	8.91
2			0.03	0.07	0.15	0.31	0.65	1.34	2.70
3				0.01	0.02	0.04	0.10	0.23	0.50
4					0.00	0.00	0.01	0.02	0.06
5						0.00	0.00	0.00	0.00
6							0.00	0.00	0.00
7								0.00	0.00
8									0.00

Table 5.47. Binomial Market Value with 100% Seed Use at $1.80 with .3 Volatility

X(i,n)	0	1	2	3	4	5	6	7	8
0	18.95	25.58	34.53	46.61	62.92	84.93	114.64	154.75	208.89
1		14.04	18.95	25.58	34.53	46.61	62.92	84.93	114.64
2			10.40	14.04	18.95	25.58	34.53	46.61	62.92
3				7.70	10.40	14.04	18.95	25.58	34.53
4					5.71	7.70	10.40	14.04	18.95
5						4.23	5.71	7.70	10.40
6							3.13	4.23	5.71
7								2.32	3.13
8									1.72

Table 5.48. F1 with 100% Seed Use at $1.80 with .3 Volatility

F_1(i,n)	0	1	2	3	4	5	6	7	8
0	3.19	5.69	9.44	14.66	21.76	31.31	44.07	60.99	83.19
1		1.69	3.11	5.62	9.36	14.53	21.51	30.78	42.97
2			0.83	1.59	2.99	5.51	9.19	14.22	20.88
3				0.36	0.73	1.46	2.84	5.30	8.82
4					0.13	0.29	0.61	1.27	2.60
5						0.04	0.09	0.20	0.45
6							0.01	0.02	0.04
7								0.00	0.00
8									0.00

Summary

Both Glenn and Faller were analyzed using NPV and real options. It was found that, using simulated data, Glenn was not profitable to produce while Faller was. Using actual data, Faller would not be produced while Glenn would. Changing the breeding costs had little effect on the outcome. Wheat prices were altered, and although it did change the mean outcome, the standard deviation was not affected.

A royalty-return structure was also run. The results indicated that, as volatility increased, so did the upward movements. This result also caused greater downward movements. With the increased value, it became more profitable to produce varieties with smaller royalties.

Royalties of $0.45 and $1.80 were also compared. It was found that, with royalty fees of $0.45, it was not as frequently profitable to produce wheat as when the returns were at $1.80. These smaller returning varieties are still produced by public research instructions because of the positive externalities to the public.

6. SUMMARY AND CONCLUSIONS

Problem

Strategic planning and investment are critical functions for operating a business. The ability of firms to invest in and introduce new and useful products such as new varieties of wheat, to the market determines the firm's success or failure. Agbiotechnology companies are tasked with selecting from thousands of potential new germplasms, a new germplasm that is technically feasible and will meet the requirements of regulators and the demands of both producers and consumers. The process contains both endogenous and exogenous risk. In the beginning of the development process, various technical uncertainties must be resolved, and later in the process, marketing and political uncertainties take center stage. The ability to reverse or shift course as market dynamics change is not available with traditional valuation methods.

Unlike real assets and real commodity options, it is difficult to accurately predict discoveries or to estimate future unit sales for research-and-development products. There is a high amount of risk and competition which imposes the use of real-option analytics to evaluate risk and aid in the ranking of selected research-and-development projects. Research-and-development outputs are highly volatile. This volatility positively influences the value of the option because high returns can be generated and lower returns can be avoided by reacting to changing conditions.

Uncertain returns of an investment in a new wheat variety can be captured using the real-option approach. In the case of germplasm development, the unknown values are the expected costs of the wheat breeding program and the expected NPV after commercialization.

The first element of uncertainty is the cost of developing a new germplasm varitety as well as the technical and regulatory requirements to bring the variety to market. Each generation in the development process has specific costs, amounts of time required, and risk attributes that are dependent on the characteristics of the individual breeding program.

The second source of uncertainty is the expected NPV in post-commercialization. The decision maker must be able to accurately forecast changes in yield, protein, and DON resistance along with domestic and international adoption rates. Understanding these things is needed to develop an accurate valuation framework.

There are two primary problems associated with valuing germplasm. First, the expected cash flow from commercializing germplasm characteristics is uncertain. The decision maker must be able to accurately forecast the germplasm value based on domestic and international adoption rates, along with the improvement of the germplasm itself. Additionally, the structure of the wheat-breeding industry affects uncertainty with competing products and the technology charge for genetically modified seed. Product demand and price need to be accounted for to develop an accurate valuation framework.

The second problem is the cost of developing the germplasm. There are specific risks and costs attributed to each phase in the development process. A useable model must all these uncertainties into account.

Objectives

The purpose of this thesis was to determine the option value of germplasm using the stochastic, binomial real-options approach. The efficiency gained was measured with the change in discount rates, wheat prices, protein prices and costs. These results are then used as a decision factor in determining the variety's value at different development stages.

The primary objective of this thesis was to best capture the risk and uncertainties associated with the research-and-development phases of germplasm and to value them using the real-option approach. Because the real-option approach indicated if the investment was in-the-money or out-of-the-money, management can compare "option values" calculated by this thesis' model before making the actual decision. This thesis used documented sources and current industry trends to address investment decisions.

Option values for germplasm are based on expected changes in yield, protein, and DON resistance. In order to calculate values that best represent the possible increases in value, we determined the market area, shares, and desirable attributes. These items were combined to create an NPV for the variety, which was then used as an input in a real-option model.

This study provides insight about how the real-options methodology can be applied to investment decisions about the research and development of germplasm while best capturing risks and uncertainties. The theoretical model of binomial options was developed in Chapter 3. Methodology and results were presented in Chapter 4. The option model and results were presented in Chapter 5.

Procedures

A stochastic, binomial, compound option model was used in this thesis to illustrate option values of the research project for any variety of wheat considered. Literature about variety and germplasm development, biotechnology, research and development, and the real-options methodology was used to develop a general model for the risk-and-reward profile of the germplasm development process. Expected values of 15 years of post-commercialization were used to calculate the NPV, and the binomial option tree was then derived using a backward induction process.

Real-Option Model

The stochastic, binomial, compound option model approach was used to illustrate the option values of wheat germplasm. Two possible options to “continue” and “wait” were modeled for each node. A new option tree was modeled at every point where there was a possibility of waiting. The option to “wait” was then modeled in a pair with the option to “continue” in a separate tree, denoting another possible pathway. Such representation of the model lays out the possible option values of germplasm at different development stages, depending on the kind of choices made at different points in time. The stochastic, binomial, compound option model approach is based on Amram and Kulatilaka (1999), Flagg (2008), Jägle (1999), and Guthrie, (2009).

Results: Overview

Glenn

The NPV of Glenn was found using both Ex-Ante and Ex-Post simulations. Ex-Ante used simulated data. Ex-Post used actual data. The results are shown in Table 6.1.

Using the real-option methodology after determining the NPV of Glenn through Ex-Ante simulations, it was determined that Glenn would not have been profitable to begin research until after 10 years of upward movements. Using actual data, it was proven that Glenn was actually quite profitable to produce from time 0. The Ex Ante binomial option tree is shown in Table 6.2. The Ex-Post binomial option tree is shown in Table 6.3.

Table 6.1. Glenn Results

Glenn Results (in millions)		
	Ex Ante	Ex Post
NPV	1.1	139
Yield	-52	-80
Protein	50	227
DON	2.6	0
Flour Extraction	-	-20
Flour Absorption	-	8.8

Table 6.2. Ex Ante Binomial Option Tree

X(i,n)	0	1	2	3	4	5	6	7	8
0	1.09	1.32	1.59	1.92	2.31	2.78	3.36	4.05	4.88
1		0.91	1.09	1.32	1.59	1.92	2.31	2.78	3.36
2			0.75	0.91	1.09	1.32	1.59	1.92	2.31
3				0.62	0.75	0.91	1.09	1.32	1.59
4					0.52	0.62	0.75	0.91	1.09
5						0.43	0.52	0.62	0.75
6							0.36	0.43	0.52
7								0.30	0.36
8									0.25

Table 6.3. Ex Post Glenn Binomial Option Tree

X(i,n)	0	1	2	3	4	5	6	7	8
0	136.14	164.10	197.82	238.45	287.44	346.49	417.68	503.48	606.92
1		112.93	136.14	164.10	197.82	238.45	287.44	346.49	417.68
2			93.69	112.93	136.14	164.10	197.82	238.45	287.44
3				77.72	93.69	112.93	136.14	164.10	197.82
4					64.47	77.72	93.69	112.93	136.14
5						53.49	64.47	77.72	93.69
6							44.37	53.49	64.47
7								36.81	44.37
8									30.54

Faller

Using the real-option methodology after determining the NPV of Faller, there were mixed results. The NPV using Ex-Ante and Ex-Post data is shown in Table 6.4. Ex-Ante used simulated data while Ex-Post used actual data. The binomial option tree for Ex-Ante Faller is shown in Table 6.5. The binomial option tree for Ex-Post Faller is shown in Table 6.6.

Table 6.4. Faller Results

Faller Results (in millions)		
	Ex Ante	Ex Post
NPV	218	-151
Yield	251	84
Protein	-34	-241
DON	1.1	0
Flour Extraction	-	33
Flour Absorption	-	-27

Table 6.5. Ex Ante Faller Binomial Option Tree

X(i,n)	0	1	2	3	4	5	6	7	8
0	217.52	224.64	231.98	239.57	247.40	255.50	263.85	272.48	281.39
1		210.63	217.52	224.64	231.98	239.57	247.40	255.50	263.85
2			203.96	210.63	217.52	224.64	231.98	239.57	247.40
3				197.50	203.96	210.63	217.52	224.64	231.98
4					191.25	197.50	203.96	210.63	217.52
5						185.19	191.25	197.50	203.96
6							179.33	185.19	191.25
7								173.65	179.33
8									168.15

Table 6.6. Ex Post Faller Binomial Option Tree

X(i,n)	0	1	2	3	4	5	6	7	8
0	-151.2	-156.1	-161.2	-166.5	-172.0	-177.6	-183.4	-189.4	-195.6
1		-146.4	-151.2	-156.1	-161.2	-166.5	-172.0	-177.6	-183.4
2			-141.8	-146.4	-151.2	-156.1	-161.2	-166.5	-172.0
3				-137.3	-141.8	-146.4	-151.2	-156.1	-161.2
4					-132.9	-137.3	-141.8	-146.4	-151.2
5						-128.7	-132.9	-137.3	-141.8
6							-124.6	-128.7	-132.9
7								-120.7	-124.6
8									-116.9

Royalty Income

The royalty incomes for breeding intuitions were also examined. These results are important numbers because they are the returns decision makers may potentially get for creating a new variety. Results are shown in Table 6.7. The most profit would go to an institution with a 100% seed use ratio with a $1.80 royalty fee. This result is why the private sector finds it profitable to continue to research and develop germplasm. Public institutions with smaller royalty fees and seed-use ratios still produce wheat because of the positive externalities received by the public.

Table 6.7. Royalty Income

Royalty Income	
30% seed use at $0.45	$1,421,213
30% seed use at $1.80	$5,684,853
100% seed use at $1.80	$18,949,510

Managerial Implications

The analysis and results from this thesis show that there is more value for managers who make choices as the research unfolds. Some of the option values for germplasm suggest that management should decide to continue investing during all stages of germplasm development. However, it was found that, in some cases, germplasm option values were not considered valuable enough to continue at time zero, but they became more valuable in the future, thus the decision maker should continue. This result suggests that, if the decisions are only made at the beginning stages, management is not likely to invest in germplasm development which would have been potentially beneficial.

There is also a difference between NPV and real-option analysis. NPV gives the net present value of a project at one discrete point in time. Real-options analysis, on the other hand, shows you potential values with increases or decreases in germplasm value. Because of the additional flexibility and knowledge, this flexibility makes real options more valuable.

Contributions, Limitations, and Further Research

This thesis contributes to modeling various option values in an option tree at each node, presenting such option trees, where each option tree represents a possible pathway. The nodal values of the option tree are presented in the same relative time frame, thus making it helpful to compare the option values of germplasm under various scenarios.

This model differs from previous work in various ways. GM wheat was examined previously by McDonald & Siegel (1986) and Furtan et al. (2003). They were only looking at GM wheat and its externalities. This model looks at non-GM wheat and measured the value it is adding. Flagg and Wilson (2008) analyzed the five developmental stages 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 in the previous one. This model is also very similar in the fact that certain milestones have to be reached before the next stage can begin. The difference is that this model requires 11 generations instead of 5 stages. Guthrie (2009) used compound growth options to determine whether to "continue" or "wait" on an investment. For this thesis, the model was expanded to add up to 11 generations and used the NPV that was determined by @Risk.

The findings of this thesis are limited by the factor of non-availability for historical data about how many times decision makers chose the option to continue investing, abandon, or post pone during the development of a certain wheat variety. These numbers would have to be produced at a public or private germplasm research facility. These numbers, in turn, means that single-period probabilities do not suggest the likelihood of a company preferring one option over another. Second, there are no historical data, at least which are accessible or usable in the needed format for this type of analysis, about the cost of developing a new wheat variety. This number would need to be found to obtain a more exact option value. Additionally, the adoption rate and future planted acres, which help to derive the NPV and option value, are highly uncertain.

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APPENDIX

This Appendix contains tables showing option values in the base case for both Glenn and Faller.

Table A.1. Faller Binomial Tree

X(i, n)	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	217.5	224.6	232.0	239.6	247.4	255.5	263.9	272.5	281.4	290.6	300.1	309.9	320.1	330.5
1		210.6	217.5	224.6	232.0	239.6	247.4	255.5	263.9	272.5	281.4	290.6	300.1	309.9
2			204.0	210.6	217.5	224.6	232.0	239.6	247.4	255.5	263.9	272.5	281.4	290.6
3				197.5	204.0	210.6	217.5	224.6	232.0	239.6	247.4	255.5	263.9	272.5
4					191.2	197.5	204.0	210.6	217.5	224.6	232.0	239.6	247.4	255.5
5						185.2	191.2	197.5	204.0	210.6	217.5	224.6	232.0	239.6
6							179.3	185.2	191.2	197.5	204.0	210.6	217.5	224.6
7								173.6	179.3	185.2	191.2	197.5	204.0	210.6
8									168.1	173.6	179.3	185.2	191.2	197.5
9										162.8	168.1	173.6	179.3	185.2
10											157.7	162.8	168.1	173.6
11												152.7	157.7	162.8
12													147.8	152.7
13														143.2

Table A.2. Faller at F11

$F_{11}(i,n)$	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	204.9	211.6	218.5	225.7	233.0	240.7	248.5	256.7	265.1	273.7	282.7	291.9	301.5	311.4
1		198.4	204.9	211.6	218.5	225.7	233.0	240.7	248.5	256.7	265.1	273.7	282.7	291.9
2			192.1	198.4	204.9	211.6	218.5	225.7	233.0	240.7	248.5	256.7	265.1	273.7
3				186.0	192.1	198.4	204.9	211.6	218.5	225.7	233.0	240.7	248.5	256.7
4					180.1	186.0	192.1	198.4	204.9	211.6	218.5	225.7	233.0	240.7
5						174.4	180.1	186.0	192.1	198.4	204.9	211.6	218.5	225.7
6							168.9	174.4	180.1	186.0	192.1	198.4	204.9	211.6
7								163.5	168.9	174.4	180.1	186.0	192.1	198.4
8									158.3	163.5	168.9	174.4	180.1	186.0
9										153.3	158.3	163.5	168.9	174.4
10											148.5	153.3	158.3	163.5
11												143.8	148.5	153.3
12													139.2	143.8
13														134.8

Table A.3. Faller at F10

$F_{10}(i,n)$	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	191.0	197.2	203.7	210.4	217.3	224.4	231.7	239.3	247.1	255.2	263.6	272.2	281.1	290.3
1		184.9	191.0	197.2	203.7	210.4	217.3	224.4	231.7	239.3	247.1	255.2	263.6	272.2
2			179.1	184.9	191.0	197.2	203.7	210.4	217.3	224.4	231.7	239.3	247.1	255.2
3				173.4	179.1	184.9	191.0	197.2	203.7	210.4	217.3	224.4	231.7	239.3
4					167.9	173.4	179.1	184.9	191.0	197.2	203.7	210.4	217.3	224.4
5						162.6	167.9	173.4	179.1	184.9	191.0	197.2	203.7	210.4
6							157.4	162.6	167.9	173.4	179.1	184.9	191.0	197.2
7								152.4	157.4	162.6	167.9	173.4	179.1	184.9
8									147.6	152.4	157.4	162.6	167.9	173.4
9										142.9	147.6	152.4	157.4	162.6
10											138.4	142.9	147.6	152.4
11												133.8	138.2	142.8
12													128.5	132.7
13														115.4

Table A.4. Faller at F9

F_9(i, n)	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	178.0	183.8	189.9	196.1	202.5	209.1	216.0	223.1	230.4	237.9	245.7	253.8	262.1	270.7
1		172.4	178.0	183.8	189.9	196.1	202.5	209.1	216.0	223.1	230.4	237.9	245.7	253.8
2			166.9	172.4	178.0	183.8	189.9	196.1	202.5	209.1	216.0	223.1	230.4	237.9
3				161.6	166.9	172.4	178.0	183.8	189.9	196.1	202.5	209.1	216.0	223.1
4					156.5	161.6	166.9	172.4	178.0	183.8	189.9	196.1	202.5	209.1
5						151.5	156.5	161.6	166.9	172.4	178.0	183.8	189.9	196.1
6							146.7	151.5	156.5	161.6	166.9	172.4	178.0	183.8
7								142.0	146.7	151.5	156.5	161.6	166.9	172.4
8									137.5	142.0	146.7	151.5	156.5	161.6
9										133.1	137.5	142.0	146.6	151.4
10											128.5	132.7	137.1	141.5
11												122.0	126.0	130.2
12													104.9	108.3
13														44.8

Table A.5. Faller at F8

$F_8(i, n)$	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	165.9	171.3	177.0	182.8	188.8	194.9	201.3	207.9	214.8	221.8	229.1	236.6	244.3	252.3
1		160.6	165.9	171.3	177.0	182.8	188.8	194.9	201.3	207.9	214.8	221.8	229.1	236.6
2			155.5	160.6	165.9	171.3	177.0	182.8	188.8	194.9	201.3	207.9	214.8	221.8
3				150.6	155.5	160.6	165.9	171.3	177.0	182.8	188.8	194.9	201.3	207.9
4					145.8	150.6	155.5	160.6	165.9	171.3	177.0	182.8	188.8	194.9
5						141.2	145.8	150.6	155.5	160.6	165.9	171.3	177.0	182.8
6							136.7	141.2	145.8	150.6	155.5	160.6	165.9	171.3
7								132.3	136.7	141.1	145.8	150.6	155.5	160.6
8									128.0	132.2	136.5	141.0	145.6	150.4
9										123.2	127.3	131.4	135.8	140.2
10											115.8	119.6	123.5	127.6
11												97.1	100.3	103.6
12													48.7	50.3
13														12.8

Table A.6. Faller at F7

F_7(i, n)	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	156.1	161.3	166.6	172.0	177.7	183.5	189.5	195.8	202.2	208.8	215.7	222.7	230.0	237.6
1		151.2	156.1	161.3	166.6	172.0	177.7	183.5	189.5	195.8	202.2	208.8	215.7	222.7
2			146.4	151.2	156.1	161.3	166.6	172.0	177.7	183.5	189.5	195.8	202.2	208.8
3				141.7	146.4	151.2	156.1	161.3	166.6	172.0	177.7	183.5	189.5	195.8
4					137.2	141.7	146.4	151.2	156.1	161.3	166.6	172.0	177.7	183.5
5						132.8	137.2	141.7	146.4	151.2	156.1	161.3	166.6	172.0
6							128.6	132.8	137.2	141.7	146.4	151.2	156.1	161.2
7								124.4	128.5	132.7	137.1	141.6	146.2	151.0
8									119.9	123.8	127.9	132.1	136.4	140.9
9										113.2	116.9	120.7	124.7	128.8
10											97.1	100.3	103.6	107.0
11												55.7	57.5	59.4
12													18.7	19.3
13														3.3

Table A.7. Faller at F6

$F_6(i, n)$	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	146.9	151.8	156.7	161.9	167.2	172.7	178.4	184.3	190.3	196.6	203.0	209.7	216.6	223.7
1		142.2	146.9	151.8	156.7	161.9	167.2	172.7	178.4	184.3	190.3	196.6	203.0	209.7
2			137.7	142.2	146.9	151.8	156.7	161.9	167.2	172.7	178.4	184.3	190.3	196.6
3				133.3	137.7	142.2	146.9	151.8	156.7	161.9	167.2	172.7	178.4	184.3
4					129.1	133.3	137.7	142.2	146.9	151.8	156.7	161.9	167.2	172.7
5						125.0	129.1	133.3	137.7	142.2	146.9	151.7	156.7	161.9
6							120.9	124.9	129.0	133.2	137.6	142.1	146.8	151.6
7								116.6	120.4	124.4	128.5	132.7	137.1	141.6
8									110.5	114.1	117.9	121.7	125.7	129.9
9										96.6	99.8	103.1	106.5	110.0
10											61.1	63.1	65.2	67.4
11												24.5	25.4	26.2
12													5.8	6.0
13														0.5

Table A.8. Faller at F5

F_5(i, n)	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	130.4	134.7	139.1	143.7	148.4	153.3	158.4	163.6	169.0	174.6	180.3	186.3	192.4	198.7
1		126.2	130.3	134.6	139.1	143.6	148.4	153.3	158.3	163.5	168.9	174.5	180.2	186.1
2			122.0	126.0	130.2	134.5	138.9	143.5	148.2	153.1	158.2	163.4	168.7	174.3
3				117.8	121.7	125.7	129.8	134.1	138.6	143.1	147.8	152.7	157.8	162.9
4					113.3	117.1	120.9	124.9	129.0	133.3	137.7	142.2	146.9	151.8
5						108.1	111.7	115.4	119.2	123.1	127.2	131.4	135.7	140.2
6							101.0	104.4	107.8	111.4	115.1	118.9	122.8	126.8
7								89.9	92.9	96.0	99.2	102.5	105.8	109.3
8									71.4	73.8	76.2	78.7	81.4	84.1
9										43.7	45.2	46.7	48.3	49.9
10											18.5	19.2	19.8	20.5
11												4.9	5.1	5.3
12													0.5	0.6
13														0.0

Table A.9. Faller at F4

F_4(i, n)	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	119.5	123.4	127.5	131.7	136.1	140.6	145.3	150.1	155.1	160.2	165.5	170.9	176.4	181.8
1		115.1	118.9	122.9	127.0	131.2	135.5	140.0	144.6	149.4	154.4	159.4	164.6	169.8
2			110.4	114.0	117.8	121.7	125.8	130.0	134.3	138.7	143.3	148.0	152.9	157.8
3				104.8	108.3	111.9	115.6	119.5	123.4	127.5	131.8	136.1	140.6	145.2
4					97.7	101.0	104.3	107.8	111.4	115.1	118.9	122.8	126.9	131.1
5						87.8	90.8	93.8	96.9	100.1	103.5	106.9	110.5	114.1
6							73.8	76.2	78.8	81.4	84.1	86.9	89.8	92.8
7								54.6	56.5	58.4	60.3	62.4	64.5	66.6
8									32.4	33.5	34.7	35.9	37.1	38.3
9										14.0	14.5	15.0	15.6	16.1
10											3.9	4.1	4.2	4.4
11												0.4	0.4	0.5
12													0.0	0.0
13														0.0

Table A.10. Faller at F3

F_3(i, n)	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	107.7	111.3	115.0	118.9	122.8	126.9	131.2	135.5	140.0	144.7	149.4	154.1	158.5	162.1
1		102.2	105.6	109.1	112.8	116.5	120.4	124.4	128.6	132.8	137.2	141.7	146.0	149.8
2			95.3	98.5	101.8	105.2	108.7	112.3	116.1	120.0	124.0	128.0	132.1	136.0
3				86.4	89.3	92.3	95.4	98.6	101.9	105.3	108.8	112.4	116.1	119.8
4					74.7	77.2	79.8	82.5	85.2	88.1	91.1	94.1	97.2	100.4
5						59.6	61.6	63.7	65.9	68.1	70.4	72.8	75.2	77.8
6							41.9	43.3	44.8	46.3	47.9	49.6	51.2	53.0
7								24.1	24.9	25.8	26.7	27.6	28.6	29.6
8									10.4	10.8	11.2	11.6	12.0	12.5
9										2.9	3.0	3.1	3.3	3.4
10											0.2	0.2	0.3	0.3
11												0.0	0.0	0.0
12													0.0	0.0
13														0.0

Table A.11. Faller at F2

F_2(i, n)	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	93.3	96.5	99.7	103.1	106.5	110.1	113.8	117.6	121.5	125.5	129.4	132.9	135.1	135.0
1		85.2	88.1	91.1	94.1	97.3	100.6	104.0	107.5	111.0	114.6	118.1	120.9	122.1
2			75.0	77.6	80.2	82.9	85.7	88.6	91.6	94.7	97.8	101.0	103.9	105.9
3				62.4	64.6	66.8	69.0	71.4	73.8	76.3	78.9	81.5	84.1	86.3
4					47.7	49.3	51.0	52.8	54.6	56.5	58.4	60.4	62.4	64.3
5						32.0	33.2	34.3	35.5	36.8	38.1	39.4	40.7	42.1
6							17.8	18.5	19.1	19.8	20.6	21.3	22.1	22.9
7								7.5	7.8	8.1	8.5	8.8	9.1	9.5
8									1.9	2.0	2.2	2.3	2.4	2.5
9										0.0	0.0	0.1	0.1	0.1
10											0.0	0.0	0.0	0.0
11												0.0	0.0	0.0
12													0.0	0.0
13														0.0

Table A.12. Faller at F1

F_1(i, n)	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	75.0	77.6	80.2	83.0	85.8	88.7	91.7	94.8	97.9	101.0	103.6	105.1	104.3	99.3
1		64.1	66.3	68.6	71.0	73.4	75.9	78.5	81.1	83.8	86.3	88.3	89.0	86.8
2			51.4	53.2	55.1	57.0	59.0	61.0	63.1	65.2	67.4	69.3	70.7	70.5
3				37.7	39.1	40.5	41.9	43.4	44.9	46.4	48.0	49.6	51.0	51.7
4					24.3	25.2	26.1	27.1	28.1	29.1	30.1	31.2	32.2	33.0
5						13.0	13.5	14.1	14.6	15.2	15.8	16.4	16.9	17.5
6							5.3	5.5	5.7	6.0	6.3	6.5	6.8	7.1
7								1.2	1.3	1.4	1.5	1.6	1.6	1.7
8									0.0	0.0	0.0	0.0	0.0	0.0
9										0.0	0.0	0.0	0.0	0.0
10											0.0	0.0	0.0	0.0
11												0.0	0.0	0.0
12													0.0	0.0
13														0.0

Table A.13. Faller at F11

Policy (i,n)	0	1	2	3	4	5	6	7	8	9	10	11
0	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
1		Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
2			Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
3				Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
4					Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
5						Continue	Continue	Continue	Continue	Continue	Continue	Continue
6							Continue	Continue	Continue	Continue	Continue	Continue
7								Continue	Continue	Continue	Continue	Continue
8									Continue	Continue	Continue	Continue
9										Continue	Continue	Continue
10											Continue	Continue

Table A.14. Faller at F10

Policy (i,n)	0	1	2	3	4	5	6	7	8	9	10	11
0	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
1		Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
2			Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
3				Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
4					Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
5						Continue	Continue	Continue	Continue	Continue	Continue	Continue
6							Continue	Continue	Continue	Continue	Continue	Continue
7								Continue	Continue	Continue	Continue	Continue
8									Continue	Continue	Continue	Continue
9										Continue	Continue	Continue
10											Continue	Continue

Table A.15. Faller at F9

Policy (i,n)	0	1	2	3	4	5	6	7	8	9	10	11
0	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
1		Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
2			Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
3				Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
4					Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
5						Continue	Continue	Continue	Continue	Continue	Continue	Continue
6							Continue	Continue	Continue	Continue	Continue	Continue
7								Continue	Continue	Continue	Continue	Continue
8									Continue	Continue	Continue	Continue
9										Continue	Continue	Continue
10											Continue	Continue

Table A.16. Faller at F8

Policy (i,n)	0	1	2	3	4	5	6	7	8	9	10	11
0	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
1		Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
2			Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
3				Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
4					Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
5						Continue	Continue	Continue	Continue	Continue	Continue	Continue
6							Continue	Continue	Continue	Continue	Continue	Continue
7								Continue	Continue	Continue	Continue	Continue
8									Continue	Continue	Continue	Continue
9										Continue	Continue	Continue
10											Continue	Continue

Table A.17. Faller at F7

Policy (i,n)	0	1	2	3	4	5	6	7	8	9	10	11
0	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
1		Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
2			Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
3				Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
4					Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
5						Continue	Continue	Continue	Continue	Continue	Continue	Continue
6							Continue	Continue	Continue	Continue	Continue	Continue
7								Continue	Continue	Continue	Continue	Continue
8									Continue	Continue	Continue	Continue
9										Continue	Continue	Continue
10											Continue	Continue

Table A.18. Faller at F6

Policy (i,n)	0	1	2	3	4	5	6	7	8	9	10	11
0	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
1		Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
2			Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
3				Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
4					Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
5						Continue	Continue	Continue	Continue	Continue	Continue	Continue
6							Continue	Continue	Continue	Continue	Continue	Continue
7								Continue	Continue	Continue	Continue	Continue
8									Continue	Continue	Continue	Continue
9										Continue	Continue	Continue
10											Continue	Continue

Table A.19. Faller at F5

Policy (i,n)	0	1	2	3	4	5	6	7	8	9	10	11
0	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
1		Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
2			Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
3				Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
4					Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
5						Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
6							Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
7								Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
8									Conti nue	Conti nue	Conti nue	Conti nue
9										Conti nue	Conti nue	Conti nue
10											Conti nue	Conti nue

Table A.20. Faller at F4

Policy (i,n)	0	1	2	3	4	5	6	7	8	9	10	11
0	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
1		Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
2			Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
3				Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
4					Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
5						Continue	Continue	Continue	Continue	Continue	Continue	Continue
6							Continue	Continue	Continue	Continue	Continue	Continue
7								Continue	Continue	Continue	Continue	Continue
8									Continue	Continue	Continue	Continue
9										Continue	Continue	Continue
10											Continue	Continue

Table A.21. Faller at F3

Policy (i,n)	0	1	2	3	4	5	6	7	8	9	10	11
0	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
1		Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
2			Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
3				Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
4					Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
5						Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
6							Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
7								Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
8									Conti nue	Conti nue	Conti nue	Conti nue
9										Conti nue	Conti nue	Conti nue
10											Conti nue	Conti nue

Table A.22. Faller at F2

Policy (i,n)	0	1	2	3	4	5	6	7	8	9	10	11
0	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
1		Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
2			Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
3				Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
4					Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
5						Continue	Continue	Continue	Continue	Continue	Continue	Continue
6							Continue	Continue	Continue	Continue	Continue	Continue
7								Continue	Continue	Continue	Continue	Continue
8									Continue	Continue	Continue	Continue
9										Continue	Continue	Continue
10											-	-

Table A.23. Faller at F1

Policy (i,n)	0	1	2	3	4	5	6	7	8	9	10	11
0	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
1		Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
2			Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
3				Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
4					Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
5						Continue	Continue	Continue	Continue	Continue	Continue	Continue
6							Continue	Continue	Continue	Continue	Continue	Continue
7								Continue	Continue	Continue	Continue	Continue
8									-	-	-	-
9										-	-	-
10											-	-

Table A.24. Glenn Binomial Tree

X(i,n)	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	1.09	1.32	1.59	1.92	2.31	2.78	3.36	4.05	4.88	5.88	7.09	8.54	10.30	12.41
1		0.91	1.09	1.32	1.59	1.92	2.31	2.78	3.36	4.05	4.88	5.88	7.09	8.54
2			0.75	0.91	1.09	1.32	1.59	1.92	2.31	2.78	3.36	4.05	4.88	5.88
3				0.62	0.75	0.91	1.09	1.32	1.59	1.92	2.31	2.78	3.36	4.05
4					0.52	0.62	0.75	0.91	1.09	1.32	1.59	1.92	2.31	2.78
5						0.43	0.52	0.62	0.75	0.91	1.09	1.32	1.59	1.92
6							0.36	0.43	0.52	0.62	0.75	0.91	1.09	1.32
7								0.30	0.36	0.43	0.52	0.62	0.75	0.91
8									0.25	0.30	0.36	0.43	0.52	0.62
9										0.20	0.25	0.30	0.36	0.43
10											0.17	0.20	0.25	0.30
11												0.14	0.17	0.20
12													0.12	0.14
13														0.10

Table A.25. Glenn at F11

F_{11}(i, n)	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	0.93	1.15	1.40	1.71	2.08	2.53	3.07	3.72	4.50	5.44	6.58	7.95	9.61	11.60
1		0.76	0.93	1.15	1.40	1.71	2.08	2.53	3.07	3.72	4.50	5.44	6.58	7.95
2			0.61	0.76	0.93	1.15	1.40	1.71	2.08	2.53	3.07	3.72	4.50	5.44
3				0.49	0.61	0.76	0.93	1.15	1.40	1.71	2.08	2.53	3.07	3.72
4					0.39	0.49	0.61	0.76	0.93	1.15	1.40	1.71	2.08	2.53
5						0.31	0.39	0.49	0.61	0.76	0.93	1.15	1.40	1.71
6							0.24	0.31	0.39	0.49	0.61	0.76	0.93	1.15
7								0.18	0.24	0.31	0.39	0.49	0.61	0.76
8									0.13	0.18	0.24	0.31	0.39	0.49
9										0.10	0.13	0.18	0.24	0.31
10											0.06	0.10	0.13	0.18
11												0.04	0.06	0.10
12													0.02	0.04
13														0.01

Table A.26. Glenn at F10

F_{10}(i, n)	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	0.75	0.95	1.19	1.48	1.82	2.24	2.74	3.35	4.08	4.96	6.02	7.30	8.84	10.70
1		0.59	0.75	0.95	1.19	1.48	1.82	2.24	2.74	3.35	4.08	4.96	6.02	7.30
2			0.45	0.59	0.75	0.95	1.19	1.48	1.82	2.24	2.74	3.35	4.08	4.96
3				0.34	0.45	0.59	0.75	0.95	1.19	1.48	1.82	2.24	2.74	3.35
4					0.25	0.34	0.45	0.59	0.75	0.95	1.19	1.48	1.82	2.24
5						0.17	0.25	0.34	0.45	0.59	0.75	0.95	1.19	1.48
6							0.11	0.17	0.25	0.34	0.45	0.59	0.75	0.95
7								0.06	0.11	0.17	0.25	0.34	0.45	0.59
8									0.03	0.06	0.11	0.17	0.25	0.34
9										0.02	0.03	0.06	0.11	0.17
10											0.01	0.02	0.03	0.06
11												0.00	0.01	0.01
12													0.00	0.00
13														0.00

Table A.27. Glenn at F9

$F_9(i,n)$	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	0.56	0.74	0.96	1.23	1.55	1.94	2.41	2.98	3.66	4.48	5.47	6.66	8.10	9.84
1		0.40	0.56	0.74	0.96	1.23	1.55	1.94	2.41	2.98	3.66	4.48	5.47	6.66
2			0.28	0.40	0.56	0.74	0.96	1.23	1.55	1.94	2.41	2.98	3.66	4.48
3				0.17	0.28	0.40	0.56	0.74	0.96	1.23	1.55	1.94	2.41	2.98
4					0.10	0.17	0.28	0.40	0.56	0.74	0.96	1.23	1.55	1.94
5						0.05	0.10	0.17	0.28	0.40	0.56	0.74	0.96	1.23
6							0.03	0.05	0.10	0.17	0.28	0.40	0.56	0.74
7								0.01	0.03	0.05	0.10	0.17	0.28	0.40
8									0.01	0.01	0.03	0.05	0.09	0.17
9										0.00	0.01	0.01	0.03	0.05
10											0.00	0.00	0.01	0.01
11												0.00	0.00	0.00
12													0.00	0.00
13														0.00

Table A.28. Glenn at F8

$F_8(i,n)$	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	0.37	0.54	0.74	0.99	1.30	1.66	2.10	2.62	3.26	4.03	4.95	6.06	7.40	9.02
1		0.22	0.37	0.54	0.74	0.99	1.30	1.66	2.10	2.62	3.26	4.03	4.95	6.06
2			0.13	0.22	0.37	0.54	0.74	0.99	1.30	1.66	2.10	2.62	3.26	4.03
3				0.07	0.13	0.22	0.37	0.54	0.74	0.99	1.30	1.66	2.10	2.62
4					0.04	0.07	0.13	0.22	0.37	0.54	0.74	0.99	1.30	1.66
5						0.02	0.04	0.07	0.13	0.22	0.37	0.54	0.74	0.99
6							0.01	0.02	0.04	0.07	0.12	0.22	0.37	0.54
7								0.00	0.01	0.02	0.03	0.07	0.12	0.22
8									0.00	0.00	0.01	0.02	0.03	0.06
9										0.00	0.00	0.00	0.01	0.01
10											0.00	0.00	0.00	0.00
11												0.00	0.00	0.00
12													0.00	0.00
13														0.00

Table A.29. Glenn at F7

F_7(i,n)	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	0.19	0.33	0.52	0.76	1.04	1.38	1.79	2.29	2.89	3.61	4.48	5.53	6.80	8.32
1		0.10	0.19	0.33	0.52	0.76	1.04	1.38	1.79	2.29	2.89	3.61	4.48	5.53
2			0.06	0.10	0.19	0.33	0.52	0.76	1.04	1.38	1.79	2.29	2.89	3.61
3				0.03	0.06	0.10	0.18	0.33	0.52	0.76	1.04	1.38	1.79	2.29
4					0.02	0.03	0.06	0.10	0.18	0.33	0.52	0.76	1.04	1.38
5						0.01	0.02	0.03	0.05	0.10	0.18	0.33	0.52	0.76
6							0.00	0.01	0.01	0.03	0.05	0.10	0.18	0.33
7								0.00	0.00	0.01	0.01	0.02	0.05	0.09
8									0.00	0.00	0.00	0.01	0.01	0.02
9										0.00	0.00	0.00	0.00	0.00
10											0.00	0.00	0.00	0.00
11												0.00	0.00	0.00
12													0.00	0.00
13														0.00

Table A.30. Glenn at F6

F_6(i,n)	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	0.09	0.16	0.28	0.50	0.77	1.09	1.48	1.95	2.51	3.19	4.01	5.00	6.19	7.63
1		0.05	0.09	0.16	0.28	0.50	0.77	1.09	1.48	1.95	2.51	3.19	4.01	5.00
2			0.03	0.05	0.09	0.16	0.28	0.50	0.77	1.09	1.48	1.95	2.51	3.19
3				0.01	0.03	0.05	0.09	0.16	0.28	0.50	0.77	1.09	1.48	1.95
4					0.01	0.01	0.02	0.05	0.08	0.16	0.28	0.50	0.77	1.09
5						0.00	0.01	0.01	0.02	0.04	0.08	0.15	0.28	0.50
6							0.00	0.00	0.01	0.01	0.02	0.04	0.08	0.15
7								0.00	0.00	0.00	0.00	0.01	0.02	0.04
8									0.00	0.00	0.00	0.00	0.00	0.01
9										0.00	0.00	0.00	0.00	0.00
10											0.00	0.00	0.00	0.00
11												0.00	0.00	0.00
12													0.00	0.00
13														0.00

Table A.31. Glenn at F5

$F_5(i,n)$	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	0.03	0.05	0.09	0.16	0.29	0.52	0.84	1.26	1.76	2.36	3.09	3.97	5.03	6.31
1		0.01	0.03	0.05	0.09	0.16	0.29	0.52	0.84	1.26	1.76	2.36	3.09	3.97
2			0.01	0.01	0.02	0.05	0.08	0.16	0.29	0.51	0.84	1.25	1.76	2.36
3				0.00	0.01	0.01	0.02	0.04	0.08	0.15	0.28	0.51	0.84	1.25
4					0.00	0.00	0.00	0.01	0.02	0.04	0.08	0.15	0.27	0.51
5						0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.07	0.14
6							0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.03
7								0.00	0.00	0.00	0.00	0.00	0.00	0.00
8									0.00	0.00	0.00	0.00	0.00	0.00
9										0.00	0.00	0.00	0.00	0.00
10											0.00	0.00	0.00	0.00
11												0.00	0.00	0.00
12													0.00	0.00
13														0.00

Table A.32. Glenn at F4

F_4(i,n)	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	0.01	0.02	0.03	0.06	0.11	0.19	0.34	0.59	1.02	1.56	2.23	3.04	4.02	5.18
1		0.00	0.01	0.01	0.03	0.05	0.10	0.18	0.33	0.59	1.01	1.56	2.23	3.03
2			0.00	0.00	0.01	0.01	0.02	0.05	0.09	0.17	0.32	0.58	1.01	1.55
3				0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.08	0.15	0.30	0.57
4					0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.06	0.13
5						0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02
6							0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7								0.00	0.00	0.00	0.00	0.00	0.00	0.00
8									0.00	0.00	0.00	0.00	0.00	0.00
9										0.00	0.00	0.00	0.00	0.00
10											0.00	0.00	0.00	0.00
11												0.00	0.00	0.00
12													0.00	0.00
13														0.00

Table A.33. Glenn at F3

$F_3(i,n)$	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	0.00	0.00	0.01	0.02	0.03	0.06	0.12	0.23	0.42	0.78	1.35	2.06	2.92	3.92
1		0.00	0.00	0.00	0.01	0.01	0.02	0.05	0.10	0.20	0.39	0.75	1.31	1.99
2			0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.08	0.17	0.35	0.70
3				0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.12
4					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
5						0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6							0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7								0.00	0.00	0.00	0.00	0.00	0.00	0.00
8									0.00	0.00	0.00	0.00	0.00	0.00
9										0.00	0.00	0.00	0.00	0.00
10											0.00	0.00	0.00	0.00
11												0.00	0.00	0.00
12													0.00	0.00
13														0.00

Table A.34. Glenn at F2

$F_2(i,n)$	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.06	0.13	0.27	0.55	1.08	1.75	2.49
1		0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.09	0.21	0.46	0.91
2			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.12
3				0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5						0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6							0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7								0.00	0.00	0.00	0.00	0.00	0.00	0.00
8									0.00	0.00	0.00	0.00	0.00	0.00
9										0.00	0.00	0.00	0.00	0.00
10											0.00	0.00	0.00	0.00
11												0.00	0.00	0.00
12													0.00	0.00
13														0.00

Table A.35. Glenn at F1

F_1(i,n)	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.11	0.25	0.60	0.98
1		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.08
2			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3				0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5						0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6							0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7								0.00	0.00	0.00	0.00	0.00	0.00	0.00
8									0.00	0.00	0.00	0.00	0.00	0.00
9										0.00	0.00	0.00	0.00	0.00
10											0.00	0.00	0.00	0.00
11												0.00	0.00	0.00
12													0.00	0.00
13														0.00

Table A.36. Glenn at F11

Policy (i,n)	0	1	2	3	4	5	6	7	8	9	10	11
0	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
1		Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
2			Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
3				Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
4					Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
5						Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
6							Conti nue	Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
7								Conti nue	Conti nue	Conti nue	Conti nue	Conti nue
8									Conti nue	Conti nue	Conti nue	Conti nue
9										Conti nue	Conti nue	Conti nue
10											Conti nue	Conti nue

Table A.37. Glenn at F10

Policy (i,n)	0	1	2	3	4	5	6	7	8	9	10	11
0	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
1		Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
2			Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
3				Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
4					Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
5						Continue	Continue	Continue	Continue	Continue	Continue	Continue
6							Continue	Continue	Continue	Continue	Continue	Continue
7								-	Continue	Continue	Continue	Continue
8									-	-	Continue	Continue
9										-	-	-
10											-	-

Table A.38. Glenn at F9

Policy (i,n)	0	1	2	3	4	5	6	7	8	9	10	11
0	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
1		Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
2			Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
3				Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
4					-	Continue	Continue	Continue	Continue	Continue	Continue	Continue
5						-	-	Continue	Continue	Continue	Continue	Continue
6							-	-	-	Continue	Continue	Continue
7								-	-	-	-	Continue
8									-	-	-	-
9										-	-	-
10											-	-

Table A.39. Glenn at F8

Policy (i,n)	0	1	2	3	4	5	6	7	8	9	10	11
0	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
1		Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
2			-	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
3				-	-	Continue	Continue	Continue	Continue	Continue	Continue	Continue
4					-	-	-	Continue	Continue	Continue	Continue	Continue
5						-	-	-	-	Continue	Continue	Continue
6							-	-	-	-	-	Continue
7								-	-	-	-	-
8									-	-	-	-
9										-	-	-
10											-	-

Table A.40. Glenn at F7

Policy(i,n)	0	1	2	3	4	5	6	7	8	9	10	11
0	-	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
1		-	-	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
2			-	-	-	Continue	Continue	Continue	Continue	Continue	Continue	Continue
3				-	-	-	-	Continue	Continue	Continue	Continue	Continue
4					-	-	-	-	-	Continue	Continue	Continue
5						-	-	-	-	-	-	Continue
6							-	-	-	-	-	-
7								-	-	-	-	-
8									-	-	-	-
9										-	-	-
10											-	-

Table A.41. Glenn at F6

Policy(i,n)	0	1	2	3	4	5	6	7	8	9	10	11
0	-	-	-	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
1		-	-	-	-	Continue	Continue	Continue	Continue	Continue	Continue	Continue
2			-	-	-	-	-	Continue	Continue	Continue	Continue	Continue
3				-	-	-	-	-	-	Continue	Continue	Continue
4					-	-	-	-	-	-	-	Continue
5						-	-	-	-	-	-	-
6							-	-	-	-	-	-
7								-	-	-	-	-
8									-	-	-	-
9										-	-	-
10											-	-

Table A.42. Glenn at F5

Policy(i,n)	0	1	2	3	4	5	6	7	8	9	10	11
0	-	-	-	-	-	Continue	Continue	Continue	Continue	Continue	Continue	Continue
1		-	-	-	-	-	-	Continue	Continue	Continue	Continue	Continue
2			-	-	-	-	-	-	-	Continue	Continue	Continue
3				-	-	-	-	-	-	-	-	Continue
4					-	-	-	-	-	-	-	-
5						-	-	-	-	-	-	-
6							-	-	-	-	-	-
7								-	-	-	-	-
8									-	-	-	-
9										-	-	-
10											-	-

Table A.43. Glenn at F4

Policy(i,n)	0	1	2	3	4	5	6	7	8	9	10	11
0	-	-	-	-	-	-	-	-	Continue	Continue	Continue	Continue
1		-	-	-	-	-	-	-	-	Continue	Continue	Continue
2			-	-	-	-	-	-	-	-	-	Continue
3				-	-	-	-	-	-	-	-	-
4					-	-	-	-	-	-	-	-
5						-	-	-	-	-	-	-
6							-	-	-	-	-	-
7								-	-	-	-	-
8									-	-	-	-
9										-	-	-
10											-	-

Table A.44. Glenn at F3

Policy(i,n)	0	1	2	3	4	5	6	7	8	9	10	11
0	-	-	-	-	-	-	-	-	-	Continue	Continue	Continue
1		-	-	-	-	-	-	-	-	-	-	Continue
2			-	-	-	-	-	-	-	-	-	-
3				-	-	-	-	-	-	-	-	-
4					-	-	-	-	-	-	-	-
5						-	-	-	-	-	-	-
6							-	-	-	-	-	-
7								-	-	-	-	-
8									-	-	-	-
9										-	-	-
10											-	-

Table A.45. Glenn at F2

Policy(i,n)	0	1	2	3	4	5	6	7	8	9	10	11
0	-	-	-	-	-	-	-	-	-	-	-	Continue
1		-	-	-	-	-	-	-	-	-	-	-
2			-	-	-	-	-	-	-	-	-	-
3				-	-	-	-	-	-	-	-	-
4					-	-	-	-	-	-	-	-
5						-	-	-	-	-	-	-
6							-	-	-	-	-	-
7								-	-	-	-	-
8									-	-	-	-
9										-	-	-
10											-	-

Table A.46. Glenn at F1

Policy(i,n)	0	1	2	3	4	5	6	7	8	9	10	11	12
0	-	-	-	-	-	-	-	-	-	-	-	-	Continue
1		-	-	-	-	-	-	-	-	-	-	-	-
2			-	-	-	-	-	-	-	-	-	-	-
3				-	-	-	-	-	-	-	-	-	-
4					-	-	-	-	-	-	-	-	-
5						-	-	-	-	-	-	-	-
6							-	-	-	-	-	-	-
7								-	-	-	-	-	-
8									-	-	-	-	-
9										-	-	-	-
10											-	-	-