University of Alberta

Valuing Agricultural Biotechnology Investments: A Real Options Approach.

by

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DEDICATION

This thesis is dedicated to my beloved wife, Mrs. Patience Anum-Laate and my children Prudence, Pearl and Penuel. Patience, may the LORD God Almighty bless you richly for the sacrifices you have made to enable me come this far in my education.

ABSTRACT

A key part of the investment decision making in a new biotechnology product development and commercialization process, is the analysis of the investment's cash flows. This thesis used the net present value (NPV) and real options (RO) approaches to evaluate a research project which involves the use of genomics technologies to develop canola meal with reduced anti-nutritional factors in Western Canada. The certainty equivalent approach is used to estimate the project's NPV at the beginning of each stage of the innovation chain. Subsequently the research project is evaluated as a series of compound call options using a specialized version of the binomial model (i.e. the quadranomial approach). Overall, the NPV analysis rejected the research project when it has not successfully passed the basic R&D stage however the RO approach did not. This study has shown that the RO models could be used to value public policy and R&D projects.

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LIST OF ABBREVIATIONS

Abbreviation	Name / Organization
NPV	Net Present Value
RO	Real Options
R&D	Research and Development
PBI	Plant Biotechnology Institute
ANF	Anti-Nutritional Factors
CAPM	Capital Asset Pricing Model
CML	Capital Market Line
DTA	Decision Tree Analysis
LSM	Least Square Monte Carlo
Max	Maximum
CNRC	National Research Council of Canada
NRC	National Research Council
IPF	Industry Partnership Facility
ROV	Estimated Compound Sequential Option Value

CHAPTER 1 INTRODUCTION

This chapter provides the background to the thesis. Secondly, a brief overview of the Canadian biotechnology sector is discussed. Next, the research problem is presented. Other topics discussed include the objectives of the thesis, the methodology used and finally how the thesis is structured.

1.1 Background

In 2003, $1.9 billion was raised as capital and invested into the Canadian biotech sector, the majority of which went to public companies leaving $242.4M going to private biotechnology companies (BIOTECanada, 2004). As of 2003, research and development (R&D) investment amounted to $2.8 billion, an increase of 115% over expenditures of $1.3 billion in R&D in 2001 (BIOTECanada 2004). Is there any justification for these large R&D investments and how can these investments be appropriately valued?

Investment as defined by economics refers to the act of incurring an immediate cost in the expectation of future rewards (Dixit and Pindyck, 1994). Most biotechnology investment decisions (and R&D projects in particular) are characterized by irreversibility and uncertainty about their future payoffs (Huchzermeier and Loch, 2001). Once money is spent, it cannot be recovered if the anticipated payoffs do not materialize. However a firm usually has some flexibility in the timing of its investment projects. It has the right, but not the obligation, to invest in a particular project at some future time of its choosing; thus it holds an option analogous to a financial call option (Dixit and Pindyck, 1994). On the contrary, if a staged investment has already been undertaken, the firm is holding an option analogous to a financial put option – the right but not an obligation to stop further financing of the project whenever market conditions change adversely.

Luehrman, (1998) pointed out that the development of real options (RO) is based on financial option pricing tools and management techniques. Options on real assets, that is the physical, human and organizational capital a firm uses are similar to options on financial assets, for example "puts" and "calls" on shares or currencies because they can at least in theory be valued using the same valuation techniques. Trigeorgis, (1993) explains that the RO approach to capital budgeting has the potential to conceptualize and even quantify the value of options from active management standpoint. This value is usually manifested as a collection of real options, either calls or puts, embedded in an investment opportunity.

To assess and quantify how much an investment in a real asset is worth is the point of real options analysis and this approach starts by recognizing that most investment opportunities have a series of managerial options. The intuition behind this approach allows decision-makers to keep investment options open when facing uncertainty and embark on those investment options after using time or more information to resolve the uncertainty. Thus after making an initial investment in a project, management can then turn its attention to other matters and wait for a signal to either continue investing or abandon the project. This flexible decision structure of options is valid in a R&D context.

Lint and Pennings, (1997) argue that R&D investments can be viewed as the price of an option on major follow-on investments. After an initial investment, management can gather more information about the progress of the project as well as the market characteristics and, based on this information, change its course of action (e.g., Dixit and Pindyck, 1994; Lint and Pennings, 1997). As with options on financial securities, this flexibility to adapt in response to new information enhances the investment opportunity's value (Kogut and Kulatilaka, 1994) by improving its upside potential while limiting downside losses relative to the initial expectations (Trigeorgis, 1997). Thus the approach provides a dynamic framework for analyzing strategic capital investments. It treats investment decision as a series of opportunities rather than a now or never type of investment decision postulated by the traditional capital budgeting valuation models such as the Net Present Value (NPV) valuation technique.

This thesis is to evaluate the valuation of agricultural biotechnology investments using real options approach. The Canadian National Research Council's Plant Biotechnology Institute (PBI) is used as a case study to demonstrate how real options approach is used to analyze agricultural biotechnology R&D investment decisions.

1.2 Overview of Canadian Biotechnology

Biotechnology is a combination of two words namely biology and technology and is broadly defined as the use of living organisms (plants, animals and microorganisms) to develop foods, medicines, and other useful products. It includes genetic engineering, cloning, and other advanced technologies. Generally biotechnology research is product-oriented and it results in the production of new and improved products, such as crop varieties, animal breeds, vaccines, pharmaceuticals, diagnostics, and bio-control agents.

The biotechnology industry in Canada consists of the following sectors namely, agriculture, aquaculture, biomaterials, bioinformatics, genomics, horticulture, food/beverage, fermentation, therapeutics, vaccines, diagnostics, environment, veterinary, forestry and many more (Canadian Biotechnology Industry Guide, 2001). This comprehensive guide to the biotechnology industry in Canada focuses on organizations using biotechnology in manufacturing, product or process development and research. Based on responses from the 2002 Biotechnology Use and Development Survey, Statistics Canada reported that there were 375 biotechnology innovative firms in 2001, an increase of 5% from the previous survey results for 1999. Ninety-four (94) of these are public companies and they are engaged in human therapeutics or diagnostics. The rest are privately owned. Distribution of these biotechnology companies as of 2001 showed that 37% are into therapeutics, 17% are in agriculture, 15% in diagnostic, 13% in food processing, 9% in environment, 3% in aquaculture, 3% in bioinformatics and the remaining 3% in natural resources (Statistics Canada, 2001). Just over half of all biotechnology innovative firms were active in the human health field (i.e. human therapeutics or diagnostics). The human health sector has grown in size from 150 firms in 1999 to 199 firms in 2001. By comparison, the agriculture sector declined in number of firms from 90 in 1999 to 67 in 2001. Statistics Canada attributes this decline to several factors, including a shift from the agriculture sector to the food-processing sector and to a ceasing of operations.

Canadian biotechnology has the potential of providing tools and methods for enhancing or suppressing genetically-controlled traits, identifying and treating genetic diseases or other abnormalities, creating more effective vaccines and other pharmaceutical agents, identifying and characterizing specific organisms, and efficiently screening organisms for specific traits. This enormous potential is therefore of great interest to both public and private firms thus the establishments of many organizations operating in the above mention sectors. Each of the biotech sectors in Canada share similar characteristics in that majority of them have very significant amount of their cash outflows as R&D expenditures. Also the initial investment cost as well as risks associated with the projects of these companies is usually very high.

One of the most striking aspects of the biotechnology industry in general is its scarcity of earnings. Most biotech companies carry losses for years, even after they have launched a new product. As a result, valuing biotech projects appears to be challenging. For example, how can market share be predicted for a startup biotech company when neither the product nor the markets exist? Yet it is still imperative that a value is estimated within a reasonable range for practical purposes such as investment decisions, raising capital, negotiating strategic alliances or even public policy and R&D programmes.

1.3 Research Problem

A key part of any major investment decision making, particularly in a new biotechnology product development and commercialization process, is the analysis of the investment's cash flows. Biotech investments often involve prolonged and substantial financial commitments made under conditions of considerable uncertainty attributed to changing market related conditions, technological and regulatory uncertainties surrounding the research and development process. The field of capital budgeting has undergone a significant change with the recognition that each investment opportunity contains 'options' that have an inherent value. Although the use of the traditional capital budgeting models such as NPV provides a major vehicle for the realization of strategic vision, these models have been criticized by many academics and practicing managers (Trigeorgis, 1993). These traditional models may underestimate project value in that they do not properly capture management's operating flexibility. Since flexibility can be a source of competitive gain, especially in both the basic and commercializing aspects of biotechnology investments, the ability to appropriately value such investments can improve manager's decision-making effectiveness and efficient allocation of scarce R&D resources.

A relatively new technique to capital budgeting is the real options approach. The real options theory is the application of financial option pricing principles and management techniques to value investments in real assets (Amram and Kulatika, 1999). This approach has the potential to include the value of the project from active management and strategic interactions using a valuation technique for financial options. Under conditions of demand and technological uncertainty, the real option approach is a potentially useful technique to evaluate investment decisions in the commercialization of agricultural biotechnology and other high-risk investments.

Although biotechnology investments exhibit similar fundamental characteristics to real options reasoning, applications of the real options approach to the biotechnology sector have received limited investigation. These applications have focused on the pharmaceutical sector. To date, the analysis of the investment decisions associated with agricultural biotechnology research projects using the real options approach is lacking in the real options literature. This thesis is motivated by this research gap. As such, the purpose of this thesis is to evaluate the feasibility of the real options methodology and how strategic managerial decision-making could impact the development and commercialization of an agricultural biotechnology product namely canola meal with reduced anti-nutritional factors (ANF).

1.4 Objectives

The overall objective of this thesis is to evaluate the feasibility of the application of real options to the analysis of an agricultural biotechnology research project. The underlying technology of this project involves a reduction of sinapine and phytate in canola meal using metabolic pathway modification via genetic engineering (Georges, 2002; Selvarag, 2002). Canola meal is the product remaining after extracting oil from the canola seed and the meal is primarily used as a protein supplement in livestock feeds.

Sinapine and phytate are anti-nutritional compounds, which inhibit digestibility of feed consumed in livestock. Levels of sinapine range from 0.7% to 3%, with about 90% of it present in the embryo (non-hull) fraction. When consumed, sinapine can cause unpleasant flavours in the meat, milk and eggs (Pearson et al., 1980). Upon consumption of larger amounts, it can cause serious growth and reproduction problems (Pearson et al., 1980). Phytate, which ranges from 2.0 - 4.0% in the seed, has both nutritional and environmental impacts (Raboy, 2001). Phytate lowers the bioavailability of mineral nutrients. It also reduces phosphorus digestibility thereby increasing phosphate in animal waste, which can pollute water systems.

The specific objectives of this thesis are:

1. Identify the types of options inherent in agricultural biotechnology investment projects.
2. Review and evaluate different valuation models and in particular those that have been applied to evaluate R&D type of investments.
3. Evaluate the project using both the traditional NPV model and the real options (RO) pricing methodology.
4. Make recommendations about the impact of strategic managerial decision-making using the valuation results.

1.5 Methodology

Generally, two types of financial options exist: options to buy a specific asset at a future point in time against a pre-determined price (call options) and options to sell a particular asset at a future point in time against a pre-determined price (put options). By transferring the analogy of financial options to strategic management, the following types of real options can be analyzed: options to abandon a project, to alter the operating scale of an investment, to open up future growth opportunities, to postpone or stage investments, and to switch within different input or output opportunities (Trigeorgis, 1996). In this thesis the focus is on real options in agricultural R&D that are a precondition to open up opportunities for future growth (call options).

To evaluate the possibility of using real option theory to value the biotechnology research and development investment in canola, a literature review is carried out in the areas of traditional capital budgeting models, real options valuation models e.g. Black-Scholes model, binomial option pricing model. The review also includes Monte Carlo simulation and regression techniques, possible real options in biotechnology R&D

projects, empirical studies on valuing biotech investments as well as the biotechnology product development process. The review is based on secondary sources such as published books, journal articles, and reports posted on the internet.

Out of these different valuation models reviewed, a specialized version of the multiplicative binomial option pricing model (i.e. quadranomial approach) is identified to quantitatively evaluate the canola meal enhancing R&D project. The project is evaluated as an American call option and later as a Bermuda option in the sensitivity analysis. The quadranomial model is chosen because it can be used to value the sequential stages identified in high risk new technology ventures. Also, the quadranomial approach allows the major risks (e.g. technical and price) that affect the value of the project to be resolved simultaneously when they are modeled separately.

1.6 Organization of the Thesis

The rest of this thesis is organized into six main chapters. Chapter 2 covers the literature review. This review focuses on financial and real option theory, how they are valued as well as different valuation models used to value biotechnology investments. In chapter 3, hypothetical case examples are developed and estimated. The main purpose is to provide working models that aid in the understanding of how agricultural biotechnology investments are valued using the NPV and RO approaches. Chapter 4 addresses a case study of a canola meal enhancing technology. This chapter starts with a discussion on the biotechnology product development process. Next, the description of the project's technology, the possible real options inherent in the canola R&D process as well as the data used for evaluating the project is presented. Chapter 5 addresses the analysis, results and discussions of the study. In Chapter 6, sensitivity analyses are performed to determine how the value of the project with and without managerial flexibility responds to the underlying assumptions and key parameters of the estimating models. Chapter 7 addresses the conclusion of the thesis. Evaluation of the models used in the analysis, the implications as well as the key issues from the study is the focus of discussion. Also the limitations of the research as well as the potential challenges of using the valuation techniques are discussed in this final chapter.

CHAPTER 2 REAL OPTION THEORY / BIOTECH VALUATION MODELS

As pointed out by Luehrman, (1998) the development of real options is based on financial option pricing tools and management techniques. This chapter focuses on what financial options are, how they are valued as well as extensions made to the financial option pricing models. Other topics discussed include the type of real options associated with project investment valuations, valuation models applicable for biotechnology investments in general as well as biotechnology R&D projects in particular.

2.1 Brief Overview of Financial Options

To appreciate what real options are all about, one needs to know how financial options operate. This section provides a general picture of what financial/stock option entails as well as its essential characteristics.

2.1.1 What are Options?

By definition, an option is the right, but not the obligation to buy (call option) or sell (put option) a specified asset at a pre-specified price on or before a pre-specified date (Barney, 2001; Trigeorgis, 1999; Hull, 1997). This means that if an investor has a stock option, he or she has the right, but not the obligation to either buy or sell the stock at the pre-specified price on or before the pre-specified date. The specified price in option terminology is referred to as the exercise or strike price whilst the pre-specified date after which the options expires is referred to as the expiration or maturity date.

The key property of options is that the holder has the right but not the obligation to fulfill the option contract. An investor can always let the expiration date go by, at which point the option is worthless. If this happens, the investor will lose the money used in paying for the option (i.e. the option premium). Also, another important point is that an option is merely a contract that deals with an underlying asset thus, options are called derivatives, which mean an option derives its value from something else (Options basic tutorial, 2002). Cox et al., (1979) pointed out that an option could be in-the-money or out-of-the money. For call options, the option is said to be in-the-money if the stock price is above the strike price (Options basic tutorial, 2002). A put option on the other hand is in-the-money when the stock price is below the strike price. The amount by which an option is in-the-money is referred to as the intrinsic value. The total cost (price) of an option is called the premium. Cox et al., (1979) noted that if an option is out of the money, the option holder could let the option expire and lose the premium (money) that was paid for the option. Participants in the options market include buyers of calls, sellers of calls, buyers of puts and sellers of puts. Participants who buy options are called holders while those who sell options are called writers (Options basic tutorial, 2002).

2.1.2 Types of Options

Financial options are classified into two main types and the classification is based on the time in which these options are exercised. The first is the European option and this option can only be exercised at the end of its maturity time. The other is the American option, which can be exercised at any time. The possibility of early exercise makes American options more valuable particularly when dividends are incorporated into the analysis. American options are more difficult to value (Hull, 1997). Combination of American and European style options is referred to as Bermuda option. Bermuda options can be exercised on predetermined dates prior to expiration. The name Bermuda was chosen because it is mid way between America and Europe (Wilmott, 2001 pp.44).

In the view of Lint and Pennings, (1997) future R&D research should aim at relaxing the assumption of European options inherent in the use of the Black and Scholes, (1973) model and introduce Bermudan or compound options. Also, some options are classified as long-term options (Options basic tutorial, 2002). Such options have a maturity time of one, two, or multiple years. These are more appealing to long-term investors.

2.1.3 Sides of an Option Contract

Every option contract has two sides namely long and short positions and these in turn have their respective terminal payoffs. Thus we have long call and long put as well as short call and short put. Buyers are said to have long position while sellers are said to have short positions (Options basic tutorial, 2002). Regarding valuation, the maximum of their respective payoffs at maturity or exercise of the option is chosen thus for:

1. long call: Max. [S-X, 0], (2.1)
2. long put: Max. [X-S, 0], (2.2)

3. short call: -Max. [S-X, 0], (2.3)

4. short put: - Max. [X-S, 0], (2.4)

where: Max = maximum, S = current value price and X = strike price.

2.1.4 Valuing Financial Options (Black-Scholes Model)

An understanding of how financial options are valued is important because the variables used to estimate the value of a particular option are the same variables used in real options valuation. Hull, (1997) explains that the value of an option depends on six variables and these are, the value of the underlying asset (S), the option's exercise price (X), the time to an option's maturity (T), the standard deviation of returns (volatility) of the underlying asset (σ), the risk-free rate (r_f) and the dividends (δ) expected during the life of the project.

Several methodologies are used to calculate an option's value when analyzing financial options. These range from using closed-form equations such as the Black-Scholes model, Monte Carlo simulation methods, lattices (for example, binomial, trinomial, quadranomial and multinomial trees), variance reduction and other numerical techniques, to using partial-differential equations, and so forth.

The Black-Scholes model is the most popular. Copeland and Antikarov, (2003) indicated that the Black-Scholes model was the beginning of hundreds of papers that priced various types of options and empirically tested their predictions. As a result it is important to bear in mind the assumptions underlying the Black-Scholes model as well as its limitations for use in real option analysis. This section briefly discusses the underlying assumptions of the model and how it is used to value financial options.

In the view of Merton, (1998) the derivation of the Black-Scholes option pricing formula makes the following five assumptions. These are:

1. Frictionless and continuous markets – this implies that there are no transaction costs in buying or selling the stock or option. Also, that there are no differential taxes and that borrowing and short selling are allowed without restriction. Markets are open all the time and transactions occur continuously.

2. Underlying asset-price dynamics – this implies that the instantaneous returns can be described by an Itô-type stochastic differential equation with continuous sample path

such as: $dV = [\alpha V - D_1(V,t)]dt + \sigma V dZ$

(2.5)

where: $V(t)$ denote the price at time t of a limited-liability asset; $\alpha \equiv$ instantaneous expected rate of return on the security, which is assumed to depend, at most on $V(t)$ and t (i.e., $\sigma^2 = \sigma^2(V,t)$); dZ is a Wiener process; and $D_1 \equiv$ dividend payment flow rate. Wiener process is a continuous-time random walk with random jumps at every point in time.

3. Default-free bond-price dynamics – this implies that returns on bonds are assumed to be described by Itô stochastic process with continuous sample paths.

4. Investor preferences and expectations – Investors are assumed to prefer more to less.

5. Functional dependence of the option-pricing formula – the option price is assumed to be a twice-continuously differentiable function of the asset price, V, default free bond prices, and time.

Black and Scholes, (1973) noted that their valuation formula is based on the assumption of ideal conditions in the market both for the stock and for the option. Some of these assumptions not discussed by Merton, (1998) are that the option is European since it can only be exercised at maturity and that the stock pays no dividends or other distributions. Also, the model is based on a normal distribution of underlying asset returns or in other words the underlying asset prices are log-normally distributed. By comparison, a lognormal distribution has a longer right tail than a normal or bell-shaped distribution. The lognormal distribution allows for a stock price distribution of between zero and infinity (i.e. no negative prices) and has an upward bias (representing the fact that a stock price can only drop 100% but can rise by more than 100%).

The Black-Scholes model for a call on a stock is algebraically expressed as follows:

$$C = SN(d_1) - \left[Xe^{-r_f T} N(d_2)\right], \qquad (2.6)$$

where: C is the value of the option, S, X, r_f and T are as defined above and N (d_1) and N (d_2) are cumulative area of d_1 and d_2 respective in a standard normal distribution. The definition of d_1 and d_2 are as follows:

$$d_1 = \frac{\ln(S/X) + (r_f + \sigma^2/2)T}{\sigma\sqrt{T}} \quad and \quad d_2 = d_1 - \sigma\sqrt{T}$$

Hull, (1997) explains that the Black-Scholes model is a tool for understanding the volatility environment and for pricing illiquid securities consistently with the market prices of actively traded securities. The model is analytically friendly thus it is universally used as a way of communicating derivative prices in the market. Above all, the Black-Scholes model can be useful in synthesizing and hence pricing and hedging more complex payoffs.

Nonetheless the Black-Scholes model has the following limitations. First it assumes that the option is European. This is not a good substitute for most real life investments (Luehrman, 1998). Second there is only one source of risk thus may not be useful in valuing biotechnology investments which are faced with more than one risk. Finally, the model assumes a single underlying asset thus may be difficult to use when valuing compound options.

2.2 Real Options Perspectives

The underlying logic of the real options (RO) framework is based on the realization that future investment opportunities are contingent on prior investment opportunities. About three main concepts regarding what a real option is can be identified when reviewing the real options literature. These are: (1) the idea of option value as a part of the total value of the firm, where it represents growth opportunities; (2) a specific investment proposal with option-like properties; and (3) choices that might pertain to one or more investment proposals.

2.2.1 Option value as part of overall value

Early interest in the concept of real options in the field of finance is often traced to Miller and Modigliani's (1961) observation that a firm's market value consists of two components. The first is the present value of those cash flows that will be generated by current productive assets. The second is the present value of growth opportunities. This claim is consistent with Myers (1977) and Myers and Turnbull (1977) which suggests that the first component stemmed from existing units of productive capacity, while the second component represents options to purchase additional units of productive capacities in future periods. When the option value is not accounted for, it can result in undervaluation of projects.

2.2.2 Specific investments with option-like properties

With the exception of a few studies for example Garner et al., (2002), which argue that growth opportunities are acquired through competitive investments, investment models in the field of finance often confine the application of option analysis to decisions regarding a single project. A common objective is to derive a robust valuation method as Black and Scholes (1973) did for financial options. Researchers in finance have thus evaluated discrete projects, such as investments in R&D or in an asset with uncertain payoffs for instance the right to drill for oil or develop land (Dixit, 1992; Majd and Pindyck, 1987; Triantis and Hodder, 1990). In these studies option value is related to the preservation of choices, meaning that a firm can take a variety of actions (scale up or down, abandon, change direction, or delay) when more information is available rather than make a full commitment to a given path at the outset of the project. Key to this concept is that the researchers doing empirical work theorize that a decision sequence is consistent with options reasoning, thus form a prediction of what is likely to occur if the decision maker is using option reasoning. They then examine whether the actual decisions are in conformity to the theorized sequence.

2.2.3 Choices that might pertain to one or more proposals

These studies focus on the decisions or choices that executives might make for example wait, expand, contract etc. as the option, rather than the asset or project about which the choice is being made. For instance, Trigeorgis, (1993, 1996 and 1999) describes the following as real options. These are the option to defer (wait), time-to-build option (the option to stage and sequence investment), option to alter operating scale (e.g to expand, contract, or shut down and restart operations), growth option, option to abandon, option to switch (e.g. inputs or outputs) and multiple interacting options. Much of the research using this definition of an option consists of analytical attempts to determine the effects of making different choices on valuation.

2.3 Synopsis of the Applications of Option-Pricing Methodology

According to Merton, (1998) the option pricing methodology over the last three decades has been used to report the prices of exchange-traded derivative securities, both futures and options. In his view these exchange markets trade options and futures on individual stocks, bonds, mutual fund portfolios, currencies and commodities like agricultural products, metals, crude oil and refinery products, and electricity among others. Also, the methodology has been applied in the purchase of real estate, acquisition of publishing and movie rights, and above all by firms in granting stock-option to key employees. In all these markets, the methodology is broadly used not only in pricing but also in measuring the risk exposure of these exchange-traded derivative securities. These applications involve financial instruments thus constitutes only one of the several categories of applications for the option pricing technology (Merton, 1998).

Merton, (1970) was among the first to recognize the possibility of extending the option pricing technology to a variety of other valuation problems. Prior to that, when the basic research leading to the Black-Scholes model was underway, options were seen as rather arcane and specialized financial instruments (Merton, 1998). Option-pricing applications that do not involve financial instruments are referred to as real options. The underlying asset involved in the RO examples is rarely traded in anything approximating a continuous market and its price is thus not continuously observable either. Merton, (1998) noted that the most developed area of RO analysis is investment decisions by firms. The RO approach have been used to analyzed investment decisions in the pharmaceutical and entertainment industry as well as in the generation of electric power and the use of the concept of modularity in the production of computers and automobiles. Other areas which have received the application of the RO valuation approach include natural resource investments, land development, government subsidies and regulation, R&D, new ventures and acquisition as well as flexible manufacturing (Trigeorgis 1993).

Huchzermeier and Loch, (2001) introduced the option of corrective action that management can take to evaluate the flexibility in R&D. They identified five example types of R&D uncertainty, in market payoffs, project budgets, product performance, market requirements and project schedules. Even though standard real options intuition states that more variability increases the value of managerial flexibility as more down side can be avoided, their results indicate that this intuition is not always correct. They argue that the structure of uncertainty resolution determines to a large extent whether variability makes flexibility valuable. Huchzermeier and Loch claim that flexibility becomes valuable if after the resolution of uncertainty a decision is made before costs or revenues occur. On the contrary, they explain that if uncertainty is resolved or costs/revenues occur after all decisions have been made, more variability may smear out contingencies and thus reduce the value of flexibility.

The results of Huchzermeier and Loch is consistent with Davis, (2002) which indicates that increasing volatility can destroy growth option value, especially for firms holding quality growth options defined as at- or in-the-money growth options. They show that increasing the volatility of the project cash flows increases the discount rate thereby decreasing the value of the asset underlying the option. Davis, (2002) concludes that the value of growth options that are out-of-the-money is likely to increase with an increase in market volatility

2.4 Real Options Associated with Project Investment Valuations

This section briefly discusses the seven main categories of real options within project-investment valuations enumerated by Trigeorgis, (1993, 1996 and 1999). The importance of a particular option is contingent on the specific characteristics of the investment project.

2.4.1 Option to Defer

The option to defer occurs when an investment decision can be postponed until some date in the future. This ability to defer or wait or put off a project investment decision gives management, or whoever is taking the decision, time to examine the course of future events and the chance to avoid costly errors if unfavorable developments occur. This option is more valuable when there is high economic uncertainty and long investment horizons. Trigeorgis, (1993) explained that the option to defer is analogous to an American call option on the gross present value of the completed project's expected operating cash flows with the exercise price being equal to the required investment outlay. This is because management holds a lease (or a call option) on the particular investment opportunity under consideration. Management only invests in the project (exercise the option) if it finds it to be beneficial. Therefore this option affords management the opportunity to benefit from the resolution of uncertainty about a project. For example, management can wait *n* number of years to see if either output prices will increase or input prices will drop significantly to justify constructing a building or a plant or developing an oil field (Trigeorgis, 1996). The option to defer is important in all natural resource extraction industries, agriculture, paper products, and real estate development, because of the high risks and the long investment horizon (Trigeorgis, 1993).

2.4.2 Time-to-Build Option (Stage Investment or Sequential Option)

The time-to-build option occurs when a project investment happens in a series of outlays. Trigeorgis, (1993) noted that the required investment cost associated with most real life projects are not incurred as a single up-front outlay but rather as a series of outlays over time. Staging investment as a series of outlays creates the option to abandon the project midstream if new information received is unfavorable. Each stage can be viewed as an option on the value of the subsequent stages thus can be valued as options on options or compound options (Trigeorgis, 1996). The ability to stop the project midstream creates the opportunity of viewing the compound option either as a call option where the investor has the option to invest in the next stage of the investment or as a put option where the investor has the possibility to stop and save the cumulative losses of the future. This option is valuable in all R&D intensive industries for example pharmaceuticals, and in highly uncertain, long-development capital intensive industries such as energy generating plants or large scale construction, and in venture capital financing.

2.4.3 Option to Alter Operating Scale

Contingent on how favorable market conditions become at any given time, management of firms can expand or contract the scale of production, accelerate or reduce resource utilization, and shut down or restart on-going projects of firms. The option to alter operating scale (i.e., expand, contract, or shut down) are typically found in natural resource industries, such as mine operations, facilities planning and construction in cyclical industries as well as in commercial real estate among others.

2.4.3.1 Option to Expand

If market conditions, for example product output prices, turn out to be more favorable than expected, the scale of operation of a project can be expanded by incurring a follow-up cost outlay. This is comparable to a call option to acquire an additional part of the base-scale (initial) project with the follow-up cost outlay or the cost to expand as the exercise price. The investment opportunity with the option to expand can be viewed as the base scale project plus a call option on future investment. Trigeorgis, (1993) explain that the option to expand may also be of strategic importance, especially if it enables the firm to capitalize on future growth opportunities. This type of option is typically found in the natural resource industry.

2.4.3.2 Option to Contract

If market conditions turn out to be more unfavorable than originally expected, management can operate below their required capacity level or even reduce the scale of operations by some percentage thereby saving part of the planned investment outlays. This flexibility to mitigate loss is analogous to a put option on part of the initial project, with the exercise price equal to the potential cost savings (Trigeorgis, 1993). This may be particularly valuable in the case of new-product introductions in uncertain markets and in choosing among technologies or plants with a different construction to maintenance cost mix.

2.4.3.3 Options to Shut Down (and Restart) Operations

If output prices are such that cash revenues that accrue to the project are not sufficient to cover variable operating costs, then, the managerial flexibility to be able to shutdown and restart operations can be valuable. In such situations, the optimal decision might be to shut down operation temporarily and restart if prices rise sufficiently. Under such conditions the firm is seen as having a portfolio of call and put options. This is because being able to temporarily shut down a project is equivalent to a put option and restarting operations when the project has been down is equivalent to a call option. With regards to the call option, Trigeorgis, (1993) noted that the operations in each year could be viewed as a call option to acquire that year's cash revenues by paying an exercise price which is equivalent to the variable costs of operating. The option to shutdown and restart operations must be exercised with care since it could lead to erosion of valuable expertise that could be used elsewhere in the business (Trigeorgis, 1999).

2.4.4 Option to Abandon

This option allows a firm to abandon current operations of a project permanently if market conditions decline severely, in order to, realize the resale value of capital equipment and other assets on secondhand markets. For example if output prices suffer a sustainable decline, management may not continue to incur the fixed cost associated with the project and thus may have a valuable option to abandon the project permanently in exchange for its salvage value or halt operating losses. This option can be valued as an American put option on the project's current value with an exercise price equal to the salvage value. Abandonment options are important in capital-intensive industries where the possibility of capturing resale value for assets is high. They are also important where new products are to be introduced in uncertain markets.

2.4.5 Option to Switch

The option to switch (e.g. inputs or outputs) allows management to change either the input mix (process flexibility) or output mix (product flexibility) of a facility if prices and demand conditions change. This option provides a valuable built-in flexibility to switch from the current input to the cheapest future input, or from the current output to the most profitable future product mix, as the relative prices of input or output fluctuate over time. Depending on the market, the firm should be willing to pay a certain positive premium for a flexible technology that can change the inputs from expensive to cheap and change the output from cheap to expensive. This type of option may be more valuable in industries such as automobiles, consumer electronics, pharmaceutical, and oil industries.

2.4.6 Growth Option

Growth options occur when an early investment project of a company serves as a prerequisite or as a link in a chain of interrelated projects to open up other investment opportunities in the future. It is worth noting that unless the firm makes that early or initial investment, subsequent generations or other applications would not even be feasible. Any investment project whose implementation can be deferred, or that can be modified by the company or that creates new investment opportunities can be analyzed using the growth options framework (Kester, 1984). Like call options on securities, growth options represent real value to those companies fortunate enough to possess them. Trigeorgis, (1993) indicated that growth options can be described as another version of the option to expand and this option is of considerable strategic importance. This type of option is important in all infrastructure based or strategic industries especially high technology, R&D, or industries with multiple product generations or applications and in strategic acquisitions.

2.4.7 Multiple Interacting Options

Often, real life projects involve a combination of upward potential enhancing call options and downward protection put options (Trigeorgis, 1993). These options may interact; therefore their combined option value may differ from the alternative of evaluating each option separately and adding their values. According to Trigeorgis (1993), and Copeland and Antikarov (2003), the incremental value of an additional option, in the presence of other options, is generally less than its value in isolation, and that total option value declines as more options are present. This observation means that an investor needs to look at only a few more critical options when evaluating multiple interacting options.

2.5 Solution Methods for Calculating Option Values

Amram and Kulatika, (1999) noted that there are three general solution methods or mathematical techniques for calculating the value of an option and these methods emanate from the fields of applied mathematics and engineering. These are:

- The partial differential approach.

- The simulation approach.
- The dynamic programming approach.

These solution methods use either analytic or numerical procedures to calculate the value of an option. For many real options applications, if the inputs and application frame are correctly structured i.e. if the stochastic processes, the payoff function and decision rules are correctly specified mathematically, the three solution methods above are supposed to yield the same results within the bounds of computational precision. The intuition behind these solution methods are discussed below.

Partial Differential Approach

Calculating the value of an option using the partial differential equation approach is based on the mathematical expression of the option value and its dynamics by a partial differential equation and boundary conditions. While the equation relates the continuously changing value of the option to observable changes in market securities, the boundary conditions specify the particular option to be valued as well as its value at known points and extreme points.

The partial differential equations are solved by using analytical solutions or numerical solutions. With regards to the analytical solution, the option value is written in one equation as a direct function of the inputs. An example of the analytic solution model is the Black-Scholes model. In most cases solving analytically becomes impossible (Wilmott, 2001). Thus numerical solutions, for example Finite Difference methods, are applied by converting the partial differential equations into a set of equations that must hold over short time periods and subsequently using computational algorithms to search for the option value that solves the equations simultaneously[1]. An example of the Finite Difference method is the Binomial option pricing model. The Binomial model is a subset of the explicit Finite Difference method (Wilmott, 2001).

Simulation Approach

Simulation models on the other hand are used to solve path dependent options, in which the value of option depends not only on the value of the underlying asset but also

[1] For discussion on the pros and cons of numerical solutions interested readers should read Amram and Kulatika, (1999) pp. 109-110.

on the particular path followed by the asset. These models essentially roll out several possible paths of the evolution of the underlying asset from the present to the final decision date of the option. A common example of this model is Monte Carlo simulation. Monte Carlo simulation can also be used to solve non-path dependent options.

Dynamic Programming Approach

Dynamic programming solves the problem of how to make optimal decisions when the current decision influences future payoffs (Amram and Kulatika, 1999). This solution method rolls out possible value of the underlying asset during the life of the option and then folds back the value of the optimal decision in the future. According to Dixit and Pindyck, (1994) dynamic programming is particularly useful in dealing with uncertainty and the approach breaks the whole chain of decisions into just two components: the immediate decision, and a valuation function that sum up the consequences of all subsequent decisions, starting with the position that results from the immediate decision. The risk-neutral approach to valuation is used and the optimum action is the one that maximizes the sum of these two components (Amram and Kulatika, 1999). The uncertainty is modeled using either a discrete-time Markov processes which implies that all the information relevant to the determination of the probability distribution of future values is summarized in the current value of the state variable(s) under consideration or continuous-time.

Central to dynamic programming is the Bellman's principle which defines the optimal strategy as follows. Given the choice of the initial strategy, the optimal strategy in the next period is the one that would be chosen if the entire analysis were to begin in the next period. Thus the approach refers to a systematic method by which the present values that results from immediate investment are compared with that from waiting or continuation irrespective of whether the planning horizon is finite or infinite in order to determine an optimum action.

Dynamic programming has the advantage of handling complex decision structures (including constraints), complex relationships between the value of the option and the value of the underlying asset as well as complicated form of leakage, such as those that vary with time and the value of the underlying asset (Amram and Kulatika, 1999). These advantages are also present in the binomial model. In the view of Huchzermeier and Loch

(2001) dynamic programming does not require asset replication which is typical of contingent claims analysis. Smith and McCardle (1998) propose a methodology for oil exploration projects by using option pricing for risks that can be replicated in the market and dynamic programming for risks that cannot be replicated. The limitation of the dynamic programming approach is that it does not address the question of the correct risk-adjusted discount rate (Huchzermeier and Loch 2001).

The choice of any particular solution method should be based on the nature and characteristics of the investment project under consideration. The canola project is faced with two major risks and the investment costs of the project is not incurred at once as a lump sum but rather in phases over a certain period of time. These characteristics of the canola meal enhancing technology can be modeled by using the quadranomial model. Simulation and dynamic programming approaches were rejected on account of the following. Firstly, when there are two or more sources of risk, modeling via simulation is quite complex. Secondly, Amram and Kulatika, (1999) pointed out that the advantages of the dynamic programming approach is present in the binomial model.

2.6 Valuation Models Applicable to Biotechnology Investments

It is worth noting that for any valuation exercise, the method selected should be suitable for the specific company, project or investment under consideration. For biotech valuation, three main approaches that are generally appropriate are: (1) discounted cash flow analyses, (2) Monte Carlo simulation models, and (3) option pricing models (Bractic et al., 2000). Glennerster and Kremer, (2001) used a discounted cash flow approach (NPV) to value vaccine purchase commitment. Their analysis focused on the cash flows associated with the delivery of vaccines and not on the valuation of R&D to the firm. A review of some of the empirical literatures on valuing biotechnology investments show that these general approaches are sometimes used in combination. For example Cobb and Charnes, (2003) introduced a simulation-optimization approach which relies on an "NPV

Calculation Engine"[2] to determine the value of real investment projects having several stochastic decision variables.

With regards to real option valuation models of irreversible investment, two main categories are evident following a review of some of the real options literature (Brennan and Schwartz 1985). Firstly, we have those models that assume the existence of a perfect spanning asset, the price of which is perfectly correlated with the value of the real asset. Thus the existence of a complete market is assumed. This is often termed the contingent claims approach, as standard options theory is invoked to obtain the valuation. This group of models aim at finding a self-financing portfolio whose cash flows replicate those real assets which are to be valued. Examples of the models that use this replicating portfolio type of argument include those of Copeland and Antikarov (2003), Dixit and Pindyck (1994), Pindyck (1991) and Brennan and Schwartz (1985). On the other hand, we have those models for example McDonald and Siegel (1986) which value the underlying options of the investment using equilibrium rates of return determined by the use of the Capital Asset Pricing Model (CAPM).

The rest of this section aims at providing the intuition behind these different valuation models as well as their strength and weakness with respect to the valuation of R&D investments. The models examined include:

- Discounted cash flow models
- Decision tree analysis
- Simulation models
- Binomial option pricing model

2.6.1 Discounted Cash Flow Method

There are four widely used capital budgeting techniques namely (1) payback method[3], (2) accounting rate of return, (3) internal rate of return and (4) net present value (Copeland, Weston and Shastri, 2005). Copeland, Weston and Shastri, (2005) explain that out of these four methods the net present value (NPV) method is the only technique or

[2] NPV Calculation Engine is defined as the first component of the simulation-optimization model used to calculate the NPV of the project. It makes use of three classes of underlying assumptions. For details interested readers are to refer to page 344 of the Cobb and Charnes, (2003) journal article.
[3] Even though the payback method is one of the traditional capital budgeting techniques, it is not a discounted cash flow method. This is because it does not consider the time value of money.

investment decision tool that (in a world of certainty) is consistent with shareholder wealth maximization. Maximizing shareholder's value is the main financial objective of a company and this can be achieved through effective investment decisions. All companies perform a certain type of quantitative analysis in order to identify value-increasing projects and to formulate their preferences regarding investment projects. Any investment analysis aimed at maximizing shareholder's wealth requires that (Copeland, Weston and Shastri, 2005):

1. All cash flows should be considered during the analysis.
2. The cash flows should be discounted using the opportunity cost of capital (discount rate).
3. The investment decision model adopted should be able to choose from a set of mutually exclusive projects the one that maximizes share holder's wealth.
4. Management of firms should be able to appraise one project independently from all others.

The NPV method is a traditional discounted cash flow approach to valuation. This involves multiplying the estimated future cash flows by a discount factor in order to attain the present value of an investment. The discount rate reflects two things. Firstly, the time value of money which implies that investors would rather have cash immediately than having to wait and must therefore be compensated by paying for the delay. Secondly a risk premium that reflects the extra return investors demand because they want to be compensated for the risk that the cash flow might not materialize after all. Bractic et al., (2000) indicate the importance of time in discounted cash flow analysis and argue that for the biotech industry, this involves estimating the time required to obtain product approval, bring the product to market, and to penetrate the market. In their view time magnifies uncertainty, thus using this methodology to value biotech investments may not be feasible since it takes over ten years for the market introduction of biotech products.

Copeland and Antikarov, (2003) pointed out that the NPV model is the foundation for real option analysis. The following section which provides an overview of this model is a necessary building block for this thesis. For a discussion on payback, accounting rate of return and internal rate of return methods and their limitation, interested readers are referred to Copeland, Weston and Shastri, (2005).

2.6.1.1 Net Present Value Model (NPV)

There are two main approaches for determining the NPV of an investment. Copeland and Antikarov, (2003) pointed out that it is possible to calculate the value of a project either by estimating its expected free cash flows and discounting them at a risk adjusted discount rate, or to risk-adjust the cash flows and discount them at the risk-free rate. This section provides a brief discussion of both approaches[4].

Risk Adjusted Discount Rate Approach

According to Copeland, Weston and Shastri (2005), the net present value for an investment of *N* periods is mathematically expressed as:

$$NPV = -I_0 + \frac{E(FCF_1)}{(1+r)} + \frac{E(FCF_2)}{(1+r)^2} + \ldots + \frac{E(FCF_N)}{(1+r)^N} = \sum_{t=1}^{N} \frac{E[FCF_t]}{(1+r)^t} - I_0, \qquad (2.7)$$

where:

$E(FCF_t)$ = the expected free cash flows in time period t.

r = the risk-adjusted discount rate applicable to the project.

I_0 = the required present value of the investment outlay for the project.

N = the number of years the free cash flows are received.

From equation (2.7) above, the NPV of an investment is determined by subtracting the required investment outlay from the estimated gross project value determined by discounting the expected free cash flows at the risk-adjusted discount rate applicable to the project.

Certainty-Equivalent Approach

According to Copeland and Antikarov, (2003) the certainty-equivalent approach is a common method for valuing options in lattice. This approach adjusts for risk by subtracting a penalty from the expected cash flows to first obtain certainty-equivalent cash flows. Subsequently it discounts the certainty-equivalent cash flows at the risk free rate. The certainty-equivalent approach is expressed as (Trigeorgis, 1999; Copeland and Antikarov, (2003):

[4] For a detailed discussion of both approaches interested readers are referred to Copeland and Antikarov, (2003) and other corporate finance textbooks.

$$NPV = \sum_{t=1}^{N} \frac{F\hat{C}F_t}{\left(1+r_f\right)^t} - I_0 \tag{2.8}$$

where $F\hat{C}F_t$ is the certainty-equivalent cash flow in year t. It is expressed as:

$$F\hat{C}F_t = E(FCF_t)\left(\frac{1+r_f}{1+r}\right)^t = E(FCF_t) - risk\ \ premium$$

r_f = the risk-free rate.

r = the risk-adjusted discount rate applicable to the project.

Irrespective of the approach used, the NPV is an amount that expresses how much value an investment will result in. It is the net result of a multi-year investment expressed in today's dollars. The NPV of the project is exactly the same as the increase in shareholders' wealth (Copeland, Weston and Shastri 2005).

It is worth noting that the analyst must consider cash flows and not accounting earnings in calculating the NPV and more importantly only cash flows that are relevant or incremental to the project should be used (Ross et al., 1999). Relevant cash flows refer to the incremental cash flows associated with the decision to invest in a project. The incremental cash flows refer to any and all changes in the firm's future cash flows that are a direct consequence of taking the project. Incremental cash flows do not include sunk costs, opportunity costs, side effects, and financing costs. To estimate cash inflows of a project, managers should conduct economic studies, concept tests and market analysis (IOMA, 2003). Internal forecasts made by executives and financial analysts should reflect changes in the market, government regulation and any other relevant aspect of the project.

Determination of Risk Premium

Quantifying risk is essential to NPV analysis. Every investment project has a certain level of risk associated with it. The most commonly used form of assessing risk in conventional investment theory is the Capital Asset Pricing Model (CAPM) (Copeland and Antikarov, 2003). The Capital Asset Pricing Model is an equilibrium asset pricing theory that shows that equilibrium rates of expected return on all risky assets are a function of their covariance with the market portfolio. A market premium is presumed to be paid to shareholders, above the risk-free rate, for bearing the systematic (non-diversifiable) risk associated with an industry or sector and this rate is used to discount the operating cash flows associated with a project.

Duku-Kaakyire, (2003) argued that the Capital Market Line (CML) is a more appropriate risk measure for non-diversifiable investment projects, such as investments in agriculture, thus used the CML model to determine the appropriate risk-adjusted discount rate for his pork investment analysis. CAPM, CML and other asset pricing theories are explained in detail in Copeland, Weston and Shastri, (2005).

2.6.1.2 Decision Criterion and Shortfalls of the NPV Analysis

By the NPV criterion, an investment is deemed acceptable if it has a positive NPV. The NPV approach is seen by many researchers and academicians to be superior to other traditional methods of valuation (Brigham and Gapenski, 1997; Trigeorgis, 1999). According to Brigham and Gapenski, (1997) other reasons that have facilitated the use of the NPV approach is its simplicity and the fact that it takes into consideration the time value of money.

The standard critique of the NPV model however relates to the estimation of the cash flows and the determination of the relevant risk adjusted discount rate. This problem of how to come up with expected cash flows using expected prices and expected costs as well as adjusting these cash flows using tax is crucial. It cannot be done without good judgment guided by knowledge of economic indicators, underlying technology of the investment and market conditions. In addition, the approach does not deal with management's ability to time its decisions to take maximum advantage of the riskiness in the cash flows. The NPV rule implicitly assumes that either the investment is reversible or if the investment is irreversible, it is a now or never proposition (Dixit and Pindyck, 1994).

2.6.2 Decision Tree Analysis (DTA)

Decision tree analysis is a tool that assists in choosing between several courses of action. It provides a highly effective structure within which one can lay out alternatives and investigate the possible outcomes of choosing those alternatives. The methodology also enables one to form a balanced picture of the risks and rewards associated with each possible course of action. Copeland, Weston and Shastri, (2005) noted that using this approach as a capital budgeting tool to capture the value of managerial flexibility associated with a project accounts for uncertainty and later managerial decisions. A decision tree analysis typically consists of four steps: (1) structuring the problem as a tree in which the end nodes of the branches are the payoffs associated with a particular scenario or path along the tree, (2) assigning subjective probabilities to events represented on the tree, (3) assigning payoffs for consequences (dollar or utility value associated with a particular scenario), and (4) selecting course(s) of action based on analyses.

Kellogg and Charnes, (2000) used the decision-tree method as well as a binomial-lattice method to value a pharmaceutical biotech company. They pointed out that the decision-tree method is easy to construct and calculate and also easy to communicate through the use of either tables or decision trees. Furthermore, the method incorporates the notion of an abandonment option however ignores growth options because continuous outcomes are discretized.

A major limitation of the approach is that it uses the weighted average cost of capital that is appropriate for the project without flexibility to discount project values (Copeland and Antikarov, 2003). This means that the approach assumes a constant discount rate (either the risk-free rate or the weighted average cost of capital) over the entire life of the project irrespective of whether uncertainty is clearly changing based on the changing payouts at various parts of the decision tree. Thus the DTA approach violates the law of one price (i.e. does not price projects in a way that eliminates arbitrage possibilities). The law of one price simply states that, to prevent arbitrage profits, two assets that have exactly the same payouts in every state of nature are perfect substitutes and must, therefore, have exactly the same price or value (Copeland and Antikarov, 2003). Copeland and Antikarov, (2003) argue that to correctly use the approach, an investor must use the correct risk-adjusted discount rate for the cash flows of the project with flexibility and not the discount rate for the project assuming inflexible pre-commitment.

2.6.3 Monte Carlo Simulation Approach

In cases where a number of risks drive the value of a project, an investor depending on the valuation approach may be faced with the task of combining these risks into a single risk: the distribution of returns on the project. This exercise is challenging however it can be achieved by employing simulation modeling or Monte Carlo analysis. According to Trigeorgis, (1999) Monte Carlo simulation analysis is one of the extensions often made to the static NPV analysis to capture the effect of uncertainty.

The Monte Carlo simulation analysis is a sophisticated form of mathematical analysis that allows firms to come up with a range of possibilities or outcomes for a certain set of possible actions (Nichols, 1994). Whereas financial analysts most often predict results for the total project based on isolated changes in particular variables, Monte Carlo analysis predicts results based on simultaneous changes in numerous variables. The simulation approach allows risk to be incorporated into the analysis thus provides the means of exploring the trade off between risk and returns. The information thus generated is more detailed than just a point estimate given by the static NPV analysis. It is therefore able to account for uncertainty in the main variables underlying the cash flows of a project. According to Boyle, Broadie and Glasserman (1997) the approach basically consist of the following steps:

1. Simulate sample paths of the underlying state variables (e.g., underlying asset prices and interest rates) over the relevant time horizon.
2. Evaluate the discounted cash flows of a security on each sample path, as determined by the structure of the security in question.
3. Average the discounted cash flows over sample paths.

Using Monte Carlo simulation approach has the advantage of handling complex and uncertain decision problems whilst taking into consideration the interaction of the variables with one another and across time.

Like all other methods the approach has its strength and limitations. Monte Carlo becomes increasingly attractive compared to other methods of numerical integration as the uncertain decision problems increases. Also, the method is flexible and easy to implement and modify. In addition, the increased availability of powerful computers has enhanced the attractiveness of the method. The main advantages of Monte Carlo software applications are the speed at which they arrive at calculations and their ability to summarize the data.

A number of drawbacks however characterize the approach. One critique is that for very complex problems a large number of replications may be required to obtain precise results. Also, the procedure for estimating the interdependencies is complex and time consuming thus management often assigns such calculations to professionals (Trigeorgis, 1999). Thirdly the approach cannot adequately handle the asymmetries in the distribution brought about by management's flexibility to change the course of the project if, as uncertainty gets resolved overtime, cash flow realizations differ from initial expectations (Trigeorgis, 1999). Finally the interpretation of the probability distribution of the NPV given by the simulation analysis is questionable since it is not clear how to value the risk return trade off (Evans and Olsen, 1998).

When the security prices are represented as expectations, evaluation can be conveniently done using the Monte Carlo simulation method. In modern finance, the prices of the basic securities and the underlying state variables are often modeled as continuous-time stochastic processes (Boyle, Broadie and Glasserman 1997). Given the assumption of the law of one price (i.e. no riskless profit or in other words no simultaneous purchase and selling of a security in order to profit from a differential in the price) financial economists have shown that the price of a generic derivative security can be expressed as the expected value of its discounted payoffs. This expectation is taken with respect to a transformation of the original probability measure known as the equivalent martingale measure or the risk-neutral measure (Boyle, Broadie and Glasserman 1997).

According to Longstaff and Schwartz, (2001) one of the most important problems in option pricing theory is the valuation and optimal exercise of derivatives with American-style exercise features particularly when more than one factor affects the value of the option. They argue that in situations where there are multiple factors, traditional finite difference and binomial techniques become impractical. To accurately value American options they developed and used the Least Square Monte Carlo (LSM) simulation technique. The approach consists of the use of least squares to estimate the conditional expected payoff to the option holder from continuation. This conditional expectation is estimated from the cross-sectional information in the simulation. Specifically, they regressed the ex post realized payoffs on functions of the values of the state variables or on a polynomial of the realizations of the values in the current step and used the resulting fitted value as a measure of the optimal exercise strategy along each path. The exercise date (stopping time) of the option at any time step is determined by comparing the payoff from immediate exercise with the expected value of the option one step ahead (continuation value). To estimate the continuation value, it simulates several paths of the asset values and approximates the continuation value (i.e., the expected value of the future payoff of the option calculated with respect to the conditional probability) with a suited polynomial approximation of the asset values. Once the optimal stopping times are determined for each path, the value of the option is computed by averaging the present value of the payoffs obtained by applying, for each path, the above-determined stopping rule. As observed by Longstaff and Schwartz (2001), an approximation error of the continuation value in the LSM algorithm produces a downward-biased option price estimate.

2.6.4 Binomial option pricing model

The binomial model is a subset of the explicit finite difference method. In the view of Rubinstein, (1998) the binomial model has been proved over time to be the most flexible, intuitive and popular approach to real option pricing. The model is based on the simplification that over a single period (of possibly very short duration), the underlying asset can only move from its current price to two possible levels. The model embodies the following assumptions:

1. That asset price for each time period, can move to only two possible values, one up and one down, by the amount of the up and down movement calculated using the volatility and time to expiration.

2. That the up and down parameters and volatility of the underlying asset are constant and known.
3. That the probability over time of each possible price in a risk neutral world follows a log-normal distribution.
4. That there are no taxes and transaction costs.
5. That no short selling restriction exists.
6. That in general portfolios are risk free however the value of the project is assumed to vary.

The intuition behind the Binomial model is to initially develop a tree of asset prices working forward from the present to the time of expiration of the option after which the option values are calculated working back towards present from the last decision node assuming that at each node, future optimal strategic decision can be taken. Calculation of the option value is done using the risk neutral probability. A step-by-step binomial option pricing formula makes it possible to value a project at every discrete point in time. The model is presented as follows:

$$C = f\left(S, \sigma, X, T, r_f, u, d, \Delta t\right), \tag{2.9}$$

where C is the value of the option. The first 5 parameters $\left(S, \sigma, X, T \text{ and } r_f\right)$ in the function are the same as the variables in the Black-Scholes model. The last three are the up state value (u), the down state value (d), and the time between each node(Δt). The formulae for the up move (u), down move (d) as well as the risk neutral probability (p) parameters are as follows:

$$u = e^{\sigma\sqrt{\Delta t}}, \qquad d = e^{-\sigma\sqrt{\Delta t}}, \qquad and \quad p = \frac{a-d}{u-d} \qquad where \quad a = e^{r_f \Delta t} \tag{2.10}$$

The binomial model employs two main approaches to valuing real options (Copeland and Antikarov, 2003). These are the risk neutral approach to valuation and the replicating portfolio approach. The mathematics behind using the binomial option pricing model is relatively easy as compared to other real option valuation methodologies. The trinomial, quadranomial and multinomial trees are extensions of the basic binomial model. These can be used to value compound options.

2.7 Summary of valuation models

Traditional discounted cash flow models (i.e. NPV) capture the value of the project as a flow of specified estimated cash flows. These estimated cash flows are then discounted by a chosen risk adjusted discount rate. The estimated cash flows are discounted at the risk-free rate when they have already been adjusted for risk. Subsequently, management of firms allocates available funds among value-increasing projects. The NPV model does not capture managerial flexibility in the analysis and this limitation led to the development of extensions to these models for example decision tree analysis and Monte Carlo simulation techniques. The decision tree analysis and Monte Carlo simulation techniques however gave no insights about how future decision contingencies affect the risk of the project and, as a result, its discount rate.

Black-Scholes and Merton in 1973 ushered in the contingent claim approach in valuing a claim whose payoff is contingent on the value of another asset. These models were used to report the prices of exchange-traded derivative securities, both futures and options. The financial option pricing models allow the valuation of managers' rights to control cash flows using the risk-neutral pricing techniques. Subsequently, these financial option pricing principles and management techniques were applied to value investments in real assets and this is now referred to as the real option pricing models. The Black-Scholes formula is applicable to simple call or put options but not complex types of real options. Under conditions of demand and technological uncertainty, the real option approach is a potential useful technique to evaluate investment decisions in agribusiness and other high-risk investments.

The RO framework has the potential to improve managerial decision-making by providing additional insights and understanding of the investment opportunities and explains how managers can benefit from the future uncertainty of these opportunities. It also accounts for possible follow-on opportunities, provides an indication of the optimal time to exercise the option (i.e. answer the question of whether it is optimal to invest now or wait), treats investments as a collection or series of real options and above all quantifies the value of these options from active management standpoint.

Most real investments are characterized by irreversibility of the investment expenditures, uncertainty over the possible future cash flows of the project and the possibility to optimize the timing of the investment (Dixit and Pyndick, 1994). Different valuation methodologies will give preference to completely different combinations of these characteristics. R&D projects often involve compound options. This process is properly approximated by the binomial lattice model. Also, the binomial model allows for a wide range of applications and is very robust under differing conditions. In view of this the RO model that is used to evaluate the canola meal enhancing technology is based on the simplified time-discrete binomial lattice option pricing model developed by Cox et al., (1979).

CHAPTER 3 ESTIMATING THE BINOMIAL MODEL - CASE EXAMPLES

This chapter addresses how to estimate option values using the binomial model. It starts by showing how the relevant input variables are determined using hypothetical examples. Next the examples are gradually developed into agricultural biotechnology case projects. These examples are intended to illustrate solutions to the formulated cases. Above all they are intended to serve as working models for the canola R&D case study. The examples specifically indicate the relevant options embedded in the projects. A simple wait option as well as two different examples of a compound sequential option are evaluated. The first sequential option case uses a combined volatility estimate while the second keeps the risks separate, using the quadranomial approach.

3.1 Determination of Input Variables

To undertake valuation using the binomial model, the input variables that are needed include the gross present value of the project (V), the initial investment cost of the project (I), the risk-free interest rate (r_f), the volatility of the project's returns (σ), the time to maturity or expiration of the option (T) as well as the rate of dividend payment (δ). This section focuses on how these variables are determined using simple hypothetical numeric examples.

3.1.1 The Gross Project Value (V)

The gross project value (V) is the present value of the expected cash flows to be received from the project. This constitutes the sum of the expected discounted net cash flows from year one to the end of the project given by the static NPV model. Thus it excludes the initial capital cost of investment[5].

For options which are related to R&D the underlying investment is usually not traded thus an investor is faced with the problem of determining the gross project value of the R&D project. Depending on the type of innovation an investor can utilize three main approaches to overcome this problem. The first is by applying the assumption of

[5] The procedure for estimating the gross present value is the same as the first part of the NPV model presented in equation 2.7.

spanning to duplicate cash flows of a portfolio of traded assets which is correlated to the particular innovation (Dixit and Pindyck, 1994). Where spanning is not possible, an investor can either estimate the market potential for the product(s) deriving from the R&D project or estimate the future cash flow of the project and then use it as the underlying project value (Sick, 1989).

Similar to the example in Copeland and Antikarov, (2003, pp. 84) suppose a biotechnology research and development project which involves increasing current wheat yields by 20% via genetic engineering will generate expected revenue of $3,012,093 in the third year and $3,000,000 for the next seven years starting from year four. The total fixed and variable cost per year is $400,000 and $850,000 respectively. The risk-adjusted discount rate is 13%. What would be the gross present value of the project?

The gross present value of the project is calculated as follows:

$$V=\sum_{t=1}^{10}\frac{FCF_t}{(1+r)^t}=\frac{-1250000}{(1.13)^1}+\frac{-1250000}{(1.13)^2}+\frac{1762093}{(1.13)^3}+\frac{1750000}{(1.13)^4}+...+\frac{1750000}{(1.13)^{10}}=\$4,500,000 \quad (3.1)$$

where FCF_t refers to the expected free cash flows per year from the project and r is the risk adjusted discount rate. From the example above the gross present value of the project is $4,500,000. Table 3.1 shows how the spreadsheet was set up to calculate the annual free net cash flows before the estimation of the gross present value of the project.

In the instance where the project is assumed to run into perpetuity, the perpetuity value can be estimated using the formula:

$$PV = \frac{FCF}{r} \quad (3.2)$$

where FCF refers to the expected yearly cash flow and r refers to the risk adjusted discount rate. This perpetuity refers to the constant stream of identical cash flows with no end.

3.1.2 Initial Investment Cost (I)

The initial investment cost (I) refers to the present value of the start-up cost or the lump sum cost incurred at time zero (i.e. at the beginning of a project). It is worth noting that sometimes the initial investment cost is not incurred at once or as a lump sum but rather in phases over a certain period of time. A typical example of investments incurred over a certain period of time is R&D and such initial investment costs are supposed to be discounted to present during any valuation exercise. For instance, if the wheat yield-increasing biotechnology research and development project in the previous example above is expected to cost $5,000,000 over a period of three years (i.e. $1,000,000 immediately, $3,700,000 and $300,000 at the end of the first and second years respectively) the initial investment cost would be estimated as follows:

$$I = \frac{1000000}{(1.13)^0} + \frac{3700000}{(1.13)^1} + \frac{300000}{(1.13)^2} = 1000000 + \frac{3700000}{(1.13)^1} + \frac{300000}{(1.13)^2} = \$4,509,280 \quad (3.3)$$

The initial investment cost is discounted using the risk-adjusted discount rate of 13% on the assumption that the yearly costs are uncertain thus they represent expected costs. In cases where an investor is certain about the exact investment costs to be incurred each year the risk-free rate becomes a more appropriate discount rate. The spreadsheet used in calculating the present value of the investment cost is presented in Table 3.2.

Consequently, the NPV of this project is estimated by subtracting the initial investment cost determined as shown by equation (3.3) from the gross present value of the project as shown by equations (3.2). That is the NPV is given by V – I = $4,500,000-$4,509,280= -$9,280. By the NPV criterion, this biotechnology R&D project is not viable since the value is negative thus the project should be rejected.

3.1.3 Risk–Free Rate of Return (r_f)

The risk-free rate is a theoretical interest rate at which an investment may earn interest without incurring any risk. This variable refers to the risk-free interest rate for a risk-free bond with the same expiration date as the option being evaluated. In practice, the risk-free rate is often assumed to be the current bank rate of government bonds or a short-term treasury rate.

3.1.4 Volatility of the Project Returns (σ)

The volatility (σ) refers to the standard deviation of returns of the project and this measures the potential risk associated with a particular investment. Estimation of this variable is one of the challenging tasks associated with applying the real options valuation approach. Conventional applications of real options to agricultural commodities such as pork sector have used historical data to determine volatility. The underlying assumption of this conventional approach is that the future will be like the past.

Other approaches adopted to determine the volatility for biotechnology projects have used management's subjective estimates. This approach, also proposed by Copeland and Antikarov (2003), elicit information from management based on the main sources of risk for the project and then incorporate the risks into a spreadsheet set up and use Monte Carlo simulation to determine the volatility. The main sources of risk are identified and made stochastic. Depending on the characteristics of uncertainty surrounding these main sources of risk, the underlying stochastic processes are modeled as Geometric Brownian Motion or mean reversion[6].

The major risks for many biotech projects are related to technology, price, changes in regulation, competitor's moves, and so forth. According to Copeland and Antikarov, (2003) most of these risks do not get resolved smoothly as in a Brownian motion process. A classic example is the uncertainty regarding the approval of a genetically modified crop variety in the R&D pipeline. An announcement by Canadian Food Inspection Agency or the Canadian Grain Commission which approves the crop variety in question can cause its value to increase substantially or move all the way to zero if approval is denied. It becomes necessary to keep the major risks separate from each other, in such instances, in order to model their interaction and effect on the project's value explicitly. Where the major risks include price, the volatility associated with the price of the product is estimated using historical data. The procedure is as follows.

Estimating Price Volatility from Historical Data

Following Hull, (2002) the volatility of the expected return on an asset such as *V* using historical data is given by:

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(u_i - \bar{u}\right)^2} \quad where: \; u_i = \ln\left(\frac{V_i}{V_{i-1}}\right) \tag{3.4}$$

[6] For a description of the modeling of the stochastic processes interested readers should consult Copeland and Antikarov (2003: chapter 9).

σ is the volatility of the asset. u is the expected return on the asset. V_i is the asset price at the end of *ith* interval (i =0, 1… n) and n is the number of observations.

3.1.5 Time to Maturity (T)

The time to maturity (T) refers to the time left until the option disappears. Copeland and Antikarov, (2003) pointed out that the time to maturity for a project may be fixed in advance however in some cases it is subjectively defined by management as the time it takes for competitors to exploit the same opportunity.

3.1.6 Rate of Dividend Payment (δ)

The competitive pressures of the market can be modeled by incorporating dividends in the analysis. By definition, dividend payments refer to the distribution of profits to the company's shareholders. Amram and Kulatika, (1999) explain that these payments act as a leakage in value arising from cash flows that accrue between decision points. Thus the value of the underlying asset must be adjusted downwards to reflect the leakage in value from the payouts otherwise the option may not be correctly valued. A number of ways can be used to incorporate dividend payments into the binomial tree when valuing real options. Most empirical real option valuation models address two main approaches in which the underlying assets are assumed to pay either a continuous dividend yield or a discrete known dividend yield at a certain time period (Hull, 2002)[7].

Regarding the continuous dividend yield a fixed annual dividend rate is determined and the rate is incorporated into the calculation of the risk neutral probability. The formula for adjusting the binomial tree to incorporate the effect of a continuous dividend yield under the risk-neutral approach to option valuation is given as Amram and Kulatika, (1999):

$$p = \frac{\left(e^{(r_f - \delta)\Delta t} - d\right)}{(u - d)}, \qquad (3.5)$$

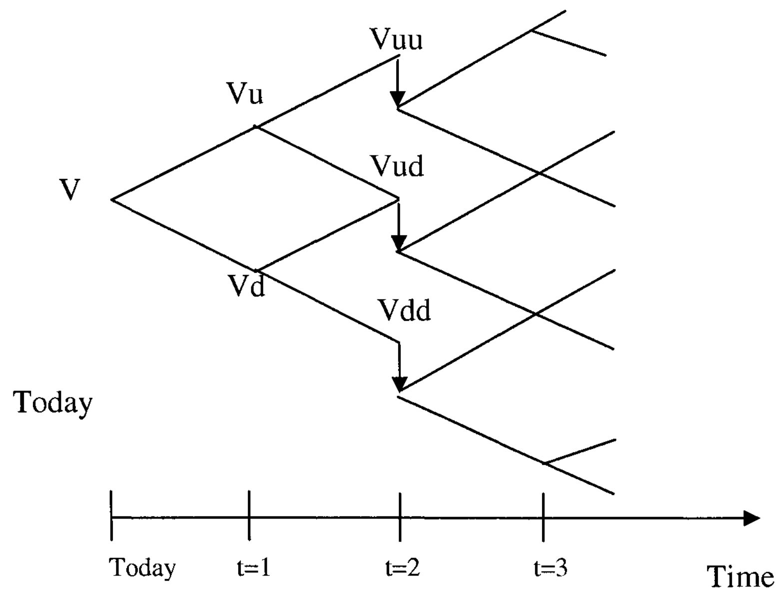
where, p denotes the new risk neutral probability incorporating the effect of dividends, e denotes exponent, r_f denotes risk-free rate, δ denotes the constant rate of payments

[7] For detailed discussion on the types of dividend adjustments interested readers are referred to Hull, (2002) and other finance textbooks.

(dividends), Δt denotes the time between each node, u denotes the up movement and d denotes the down movement.

In the case where the the underlying asset is assumed to pay a discrete known dividend yield, the value of the asset falls by the amount of the dividend on the payout date. This affects the value of the option. As a result, it may be optimal for an investor who has an American call option to exercise the option immediately before the dividend payment. However, it may be optimal for a holder of an American put option to exercise the option immediately after the dividend payment. The form of the binomial tree for a single cash payout when the option is American, is shown in Figure 3.1.

Figure 3.1 Adjusting the Option Valuation Model for a Discrete Dividend Payment when the Option is American



Source: Amram and Kulatika, (1999: pp. 133)

3.2 Valuing a Wait Option with the Basic Binomial Model - Example 1

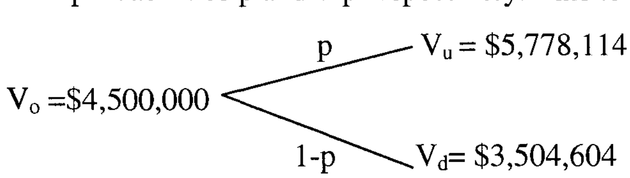
This section aims at illustrating how the above discussed input variables are applied when estimating a simple wait option using the binomial model. From sections 3.1.1 and 3.1.2 the NPV of the project determined (i.e. -$9,280) indicates that the biotech project is not worth investing in. Assuming management has a five-year option to wait in order to examine the course of future events, what will be the value of this biotech R&D project. The input variable are as follows:

- gross present value of the biotech R&D project (V) = $4,5000,000
- total investment cost (I) = $5,000,000
- project's volatility (σ) = 25%
- risk-free rate (r_f) = 5%
- continuous dividend yield (δ) = 5%
- time for option expiration (T) = 5 years
- time increments (Δt) = 1 year

It is worth noting that exercising this option to wait gives management the right but not the obligation to invest in the project and this can be viewed as a call option with an exercise price equal to the total investment cost of $5,000,000. This wait option exists for five years. To estimate this option, the given volatility (σ), risk-free interest rate (r_f), the expected continuous dividend rate (δ) and change in time period (Δt) values are substituted into equation (2.10) and equation (3.5) respectively to calculate the up move (u), down move (d) as well as the risk neutral probability (p). The calculation is done as follows.

$$u = e^{\sigma\sqrt{\Delta t}} = e^{0.25\sqrt{1}} = 1.28\,;\; d = e^{-\sigma\sqrt{\Delta t}} = e^{-0.25\sqrt{1}} = 0.78\,;\; p = \frac{e^{(r_f-\delta)\Delta t} - d}{u-d} = \frac{e^{(0.05-0.05)} - 0.78}{1.28-0.78} = 0.44$$

Subsequently, the calculated up (u) and down (d) movement parameters are used to build the projects' value tree. At each time period there are two different probabilities. The project value can either increase or decrease with probabilities, (p) and (1-p) respectively. These are derived from the assumption that the expected returns from the project is the risk-free interest rate, therefore the project value are discounted using this rate. Starting with the initial gross present value V_0 = $4,500,000 the value of the project will move over the next period either up to V_u = $5,778,114 (i.e. with a multiplicative up parameter u = 1.28) or down to V_d = $3,504,604 (i.e. with a multiplicative down parameter d = 0.78) with probabilities p and 1-p respectively. This is diagrammatically illustrated as follows:



The project value tree is presented in the top section of Table 3.3. Having determined the project's value tree, the terminal payoffs at the end of the nodes are determined by choosing the net benefit of the investment or zero whichever is larger. Similar to equation (2.1), the intrinsic value of the wait option at the top node in year 5 (see wait option payoff values in Table 3.3) is given by: C_{uuuuu} = Max. [V_{uuuuu} -I, 0] = Max. [$15,706,543 - $5,000,000, 0] = $10,706,543. This means that management invests only when the value of the project at each node is greater than the cost. Subsequently, the wait option payoff values for the rest of nodes backward to the root node at time t=0 is determined using the formula:

$$Max\ [(e^{-rf\Delta t} \times (p \times up\ option\ price + (1\text{-}p) \times down\ option\ price),\ V_{uuuuu} - I] \quad (3.6)$$

This backward calculation formula implies that moving back into the previous node, an investor determines whether to exercise the option or keep it alive until the value of the option is obtained at time t=0. As an example the calculation of the top wait option payoff value in year 4 is given by Max [($e^{-0.25 \times 1}$ × (0.44 × $10,706,543+ *(1-0.44)* × $4,526,500*)*, $12,232,268 –$5,000,000] = $7,232,268. The wait option value estimated at time t=0 is $703,775. The investment decision given by this value would be to wait. The option to wait is valuable to the project if its value at present is greater than zero.

The total value of the project with the flexibility to wait (Static NPV + Wait Option value) is given by -$9,280 + $703,775 = $694,494. This means that the value of the project with the flexibility to wait is positive. Thus the investment decision would be to wait since the project may be worth more sometime in the next five years as compared to a negative value if executed immediately.

The real options approach, besides providing a methodology for valuing strategic management, also provides information on the investment strategy to follow. At each node of the option value tree, the decision to invest, wait or abandon the project is determined as follows.

1. If Max [V_{uuuuu} –I ; Continuation value ; 0] = V_{uuuuu} –I, then **Invest** (3.7)

where $V_{uuuuu} - I$ = value of the option if exercised.

[$e^{-rf\Delta t}$ × *(p × up option price + (1-p) × down option price)]* = continuation value.

The above expression imply that if the value of the option if exercised, is greater than zero or the value of the option if unexercised (continuation value), then the optimal decision would be to exercise the option or invest in the next stage.

2. If Max [V_{uuuuu} –I ; Continuation value ; 0] = Continuation value → **Wait** (3.8)
If the continuation value is greater than zero or the value of the option if exercised the optimal decision would be to keep the option alive or wait.

3. If Max [$V_{uuuuu} - I$; Continuation value ; 0] = 0 → **Abandon or Reject** (3.9)
If either the option value if exercised or the continuation value are less than or equal to zero the optimal decision would be to abandon the project.

Using equation (3.7 to 3.9), the investment strategies associated with the top, middle and bottom wait option payoff values in year 4 (Table 3.3) are determined as follows.

- With regards to the top wait option payoff value, the value of the option if exercised (V_{uuuuu} – I) is given by $12,232,268 –$5,000,000 = $7,232,268. The value of option if unexercised (continuation value) is also given by $e^{-0.25 \times 1} \times$ [0.44 × $10,706,543+ *(1-0.44)* × $4,526,500] = $6,879,546. The abandonment value = $0. Since the value of the option if exercised is the maximum value, the investment strategy would be to exercise or invest in the project at that point.
- With regards to the middle wait option payoff value, the value of the option if exercised (V_{uuuuu} – I) is given by $4,500,000 –$5,000,000 = -$500,000. The value of option if unexercised (continuation value) is given by $e^{-0.25 \times 1} \times$ [0.44 × $778,114+ *(1-0.44)* × $0] = $324,062. The abandonment value = $0. Since the continuation is the maximum value the investment strategy would be to wait at that point.
- With regards to the bottom wait option payoff value, the value of the option if exercised and unexercised are both $0. Thus the investment strategy would be to abandon the project at that point.

The wait option value tree as well as the investment decision at various nodes of the tree is presented in the middle and bottom sections respectively of Table 3.3.

3.3 Valuing an Agricultural R&D Project with the Binomial Method - Example 2

As a continuation of the example in sections 3.1.1 and 3.1.2, suppose that a group of investors are evaluating this R&D investment project as a sequential option. They can obtain a one year option to invest in the platform basic R&D. This comprises mutagenesis (i.e. mapping the various metabolic pathways) as well as screening the selected population to ascertain the expression levels of the genes responsible for yield increase. If this basic research is conducted the price would be $1,000,000 and this option if purchased would expire one year from now. They have three years from today to make a decision on whether to develop this technology all the way to the commercialization stage. The cost of the equipments and initial operating capital required to take the technology from basic R&D to product launch is $4,000,000 and the investment in these equipments and initial operating capital is irreversible (i.e. sunk). They estimate that the platform technology could generate revenue worth 90% of the price of basic research if the project is abandoned. What would the company be willing to pay for the combined value of the basic R&D option and the related preliminary research (i.e. environmental impact assessment etc.)? Also suppose that the following are additional information from the investors NPV and Monte Carlo analysis.

- Present value of cash flows (V) = $4,500,000.
- Volatility or risk of the project (σ) = 25%.
- Risk free interest rate (r_f) = 5% per year.
- Expected continuous dividend rate (δ) = 5% per year.
- Change in time interval (Δt) = one year.

Evaluation of this investment project can be done by splitting it into two stages. The first stage investment gives the investors the right but not the obligation to invest in the platform basic R&D and this can be viewed as a call option with an exercise price equal to the cost of basic R&D given as $1,000,000. The basic R&D option exists for one year. The second stage investment gives the investors the right but not the obligation to develop this technology all the way to the commercialization stage (henceforth referred to as commercialization option) and this can also be viewed as a call option with an exercise price equal to the its cost given as $4,000,000. The time within which management should decide on whether or not to exercise this commercialization option is three years. Thus, there are two call options in a sequence. The second stage investment depends on the first stage investment because if the basic R&D is not done the investors cannot invest in the commercialization stage. If the investors decide to abandon the project after the first stage the knowledge from the basic R&D would be sold for its salvage value of $900,000 i.e. 10% below its purchase price.

At the end of time period (t=1), the first stage option expires and therefore must be exercised at the cost of basic R&D or left unexercised at no cost. If exercised, the payoff is not directly dependent on the value of the underlying project but on the value given by the option to invest at the second stage. Thus valuing this sequential compound option requires that the value of the commercialization option (second stage option) at present (i.e. time period t=0) should be first determined. This value is based on the gross present value of the project. Subsequently, the value of the option to invest in basic R&D (first stage option) is then determined based on the value tree of the option to invest in the second stage. This is because to determine whether to invest in basic R&D or not depends on the value of the final project which also depends on the second stage investment.

Using the volatility (σ), risk-free interest rate (r_f), the expected continuous dividend rate (δ) as well as the change in time period (Δt) values given above, the up move (u), the down move (d) move as well as the risk neutral probability (p) parameters are calculated using equation (2.10) and equation (3.5) respectively. The procedure for building the binomial tree for the value of the project is the same as shown in section 3.2.

Having determined the project's value tree, the terminal payoffs at the end of the nodes are determined by choosing the net benefit of the investment or zero whichever is larger. This means that the investors will invest if the value of the project is greater than the cost. Similar to equation (2.1), the rule of exercise for this call option is Max. [$Vuuu$ - I_C, 0], where (I_C) represents the investment cost associated with commercialization. The estimated terminal payoffs are shown in time period (t=3) in Table 3.4. Subsequently, the value of the commercialization option at time t=0 is determined working backwards using a similar formula as shown by equation (3.6) i.e. $Max\ [(e^{-r_f \Delta t} \times (p \times up\ option\ price + (1-p) \times down\ option\ price), Vuuu - I_C, Abandon\ value]$. This backward calculation formula implies that moving back into the previous node, an investor determines whether to exercise the option (i.e. invest in commercialization) or keep it alive until the value of the option is obtained at time t=0. Note that this formula incorporates the abandonment value because at this stage the basic R&D has already been done so the resulting knowledge can be sold for its salvage value once the investors decide to abandon the project. The value tree of the commercialization option is presented in the upper section of Table 3.4.

Following the determination of the option to invest in the second stage (commercialization option), the value of the option to invest in the first stage (basic R&D option), which is the value of the sequential compound option, is determined based on the option to commercialize value tree. Similarly, the terminal payoff for the one-year basic R&D option is estimated using the formula: max [*Vu* - I_B, 0] where *Vu* represents the commercialization option value in year 1 and (I_B) represents the investment cost for basic R&D. The basic R&D option value is estimated working backwards using the formula: *Max [(* $e^{-r_f \Delta t}$ *× (p × up option price + (1-p) × down option price),* Commercialization *option value –* I_B*, 0]*. The basic R&D option value tree is presented in lower half of Table 3.4. From Table 3.4, the value of the basic R&D option determined at time period t=0, which is the value of the compound sequential option, is estimated to be $448,702. According to Copeland and Antikarov, (2003) this compound option value is interpreted as the present value of the project today given that there are two investment phases. This value represents what the investors would have to pay for preliminary research right now given that they have the right but not the obligation to invest in basic R&D if things turn out well. Assuming the cost of investment in preliminary research before the start of the first stage of this project is greater than the value of the compound option then the optimal decision would be to abandon the project. If on the other hand the cost of investment in preliminary research today is less than the value of the compound option, the optimal strategy would be to invest in the project.

Estimation of sequential options helps management not only to determine whether it is worthwhile starting the project or to abandon midstream but also to determine the maximum amount of money they would pay for preliminary research. This option is valuable when the initial cost of investment in a project is incurred in stages. The optimal investment strategies or policy given by the estimated option values at each node of the option value tree is determined using equations (3.7) to (3.9). The bottom half of Table 3.4 show the investment policy associated with this biotechnology project.

3.4 Valuing an Agricultural R&D Project with the Binomial Method - Example 3

This section illustrates how an agricultural R&D project with two uncorrelated risks is valued. The approach used to evaluate this example is similar to the method used to evaluate the case study in chapter 5 thus it is explained in detail. In case example 2, a combined project's volatility estimate is used. The assumption behind this is that the combined project's volatility gets resolved continuously overtime. Copeland and Antikarov, (2003) noted that although this assumption is good for single projects and reflects the reality for the evolution of the market value of whole comapanies, the major risks related to projects may not be resolved smoothly over time as in a Brownian motion process. These risks are resolved only when information becomes available and the consequence is that the value of the project can dramatically move up or all the way down to zero.

Case example:

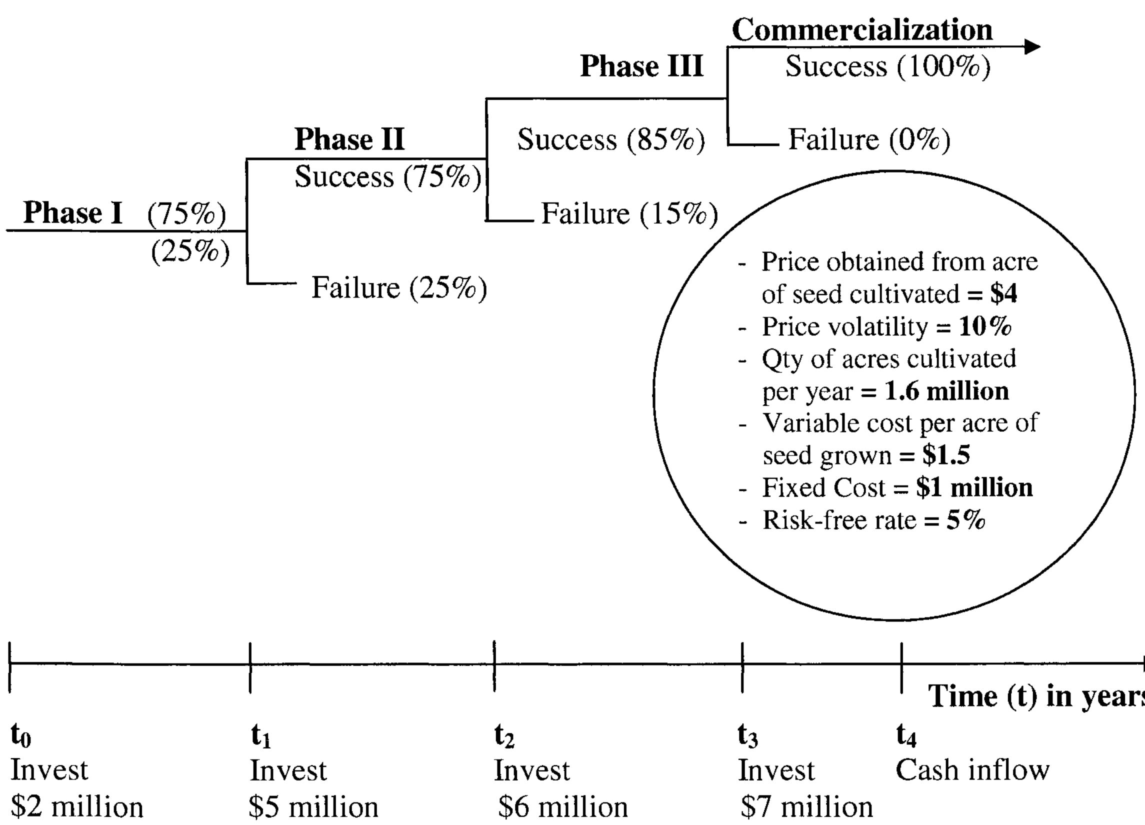
Similar to the case example in Copeland and Antikarov, (2003: pp. 324) suppose an agricultural biotech company wants to embark on a R&D development project which involves increasing current wheat yields by 20% via genetic engineering. This project is expected to go through three mandatory research phases plus an additional investment in the required production structures necessary for product launch if the new variety is approved by the regulatory agency. The R&D case example is presented in Figure 3.2.

The total investment of the project is $20 million. The investment costs associated with phase I, phase II, phase III and product launch are $2 million, $5 million, $6 million, and $7 million respectively. Technological risk constitutes the major risk associated with the project during the research phases. The technical risk arises from the success or failure at the different stages of the product development process. According to the team of research scientists at the company the probabilities of success for phase I, phase II and phase III are 75%, 75% and 85% respectively. In addition to technological risk, the company faces product price risk but these two risks are uncorrelated. Price risk is correlated with the market. Each risk is assumed to follow a geometric Brownian motion stochastic proces.

The company estimates it will receive $4 from each acre cultivated with the improved seed supposing the seed is available now. However this price can shift up or down by 10 percent at the end of each year. Also, the company estimates that if the improved seed is commercialized farmers in western Canada will cultivate 1.6 million acres each year.

Once the new wheat variety is launched in the market its value is estimated to be seven times its cash flow. Assume that the free cash flows are estimated using the relation: CF = TR – TC; where CF is free annual cash flows. TR is total revenue defined as price obtained per acre multiplied by quantity of acres cultivated per year. TC is total cost defined as variable cost per year plus fixed cost. The company's variable cost per acre of seed grown is $1.5 while the fixed cost is $1 million. The risk-free rate is 5%.

Figure 3.2 R&D Case Example



Source: Adapted from Copeland and Antikarov, (2003: pp. 327)

Valuation Approach:

A three-step numerical approach is used to value this agricultural R&D project.

1. The risks associated with the project are modeled using event trees.
2. Calculation of the base case NPV without flexibility.
3. Managerial flexibility is identified and incorporated into the analysis to calculate the real option value.

The assumption that each risk follows a geometric Brownian motion stochastic proces implies that changes in the expected value of the project are log normally distributed. Also there is a constant process variance and the expected value of the project can be approximated with a binomial tree. Since technological risk is assumed to be uncorrelated with the market, it implies that the beta of the project using the Capital Asset Pricing model (CAPM) is zero (Copeland and Antikarov, 2003). The Capital Asset Pricing model is presented in appendix A. The risk-free rate is used to discount the R&D investments. The assumption that price risk is correlated with the market implies that there are time dependencies thus cash flows obtained by commercializing the improved wheat variety cannot be discounted at the risk free rate.

To unravel this problem the quadranomial approach is used to model the risks and evaluate the project. This approach makes use of risk neutral probabilities to estimate the certainty equivalent cash flows of the project which then are discounted at the risk free rate. An alternative approach to calculate the value of the project would be to discount cash flows from the R&D phases at the risk-free rate and cash flows following product launch in the market at the weighted average cost of capital. However Copeland and Antikarov, (2003) noted that this alternative approach is ad hoc in nature and that the quadranomial approach is a more precise solution methodology. Also, the quadranomial approach allows the major risks to be resolved simultaneously (Copeland and Antikarov, 2003).

The quadranomial event tree has four branches at every node and is a straight forward generalization of the binomial event tree that has two branches at every node. Generally to build the tree, one needs an estimate of the annual standard deviations of the percent changes in the value of the asset when driven by each risk. Where the risks are correlated one needs to estimate the correlations between the risks[8]. Since the two risks in the case example are not correlated, the risk neutral probability of each branch of the quadranomial is equal to the product of the risk neutral probabilities for that branch based on each separate source of risk. This is mathematically expressed as:

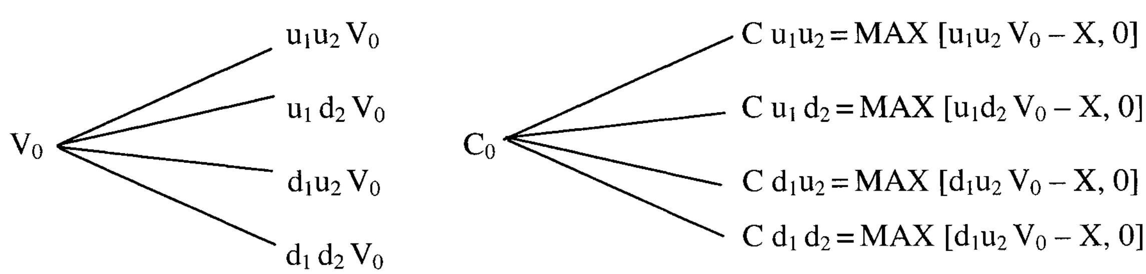
$$\begin{aligned} P_{u1u2} &= P_{u1}P_{u2} \\ P_{u1d2} &= P_{u1}P_{d2} \\ P_{d1u2} &= P_{d1}P_{u2} \\ P_{d1d2} &= P_{d1}P_{d2} \end{aligned} \qquad (3.10)$$

where P is probability, and that the multiplicative up and down movements are u_1 and d_1 when driven by the first source of risk and u_2 and d_2 when driven by the second source of risk. These four estimated risk-neutral probabilities are used in the following valuation formula to calculate the option.

$$C_0 = \frac{P_{u1u2}C_{u1u2} + P_{u1d2}C_{u1d2} + P_{d1u2}C_{d1u2} + P_{d1d2}C_{d1d2}}{(1 + r_f)}; \qquad (3.11)$$

C_0 represents value of flexibility. Figure 3.3 illustrates the quadranomial values of a risky asset as well as the associated call option after one period assuming that the starting value is V_0 and that its multiplicative up and down movements are u_1 and d_1 when driven by the first source of risk and u_2 and d_2 when driven by the second source of risk.

Figure 3.3 Quadranomial values of the risky asset and a call option after one period



Source: Copeland and Antikarov, (2003: exhibit 10.4, pp. 280).

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[8] For more discussion on this interested readers are referred to chapter 10 of Copeland and Antikarov, (2003, pp 281-286).

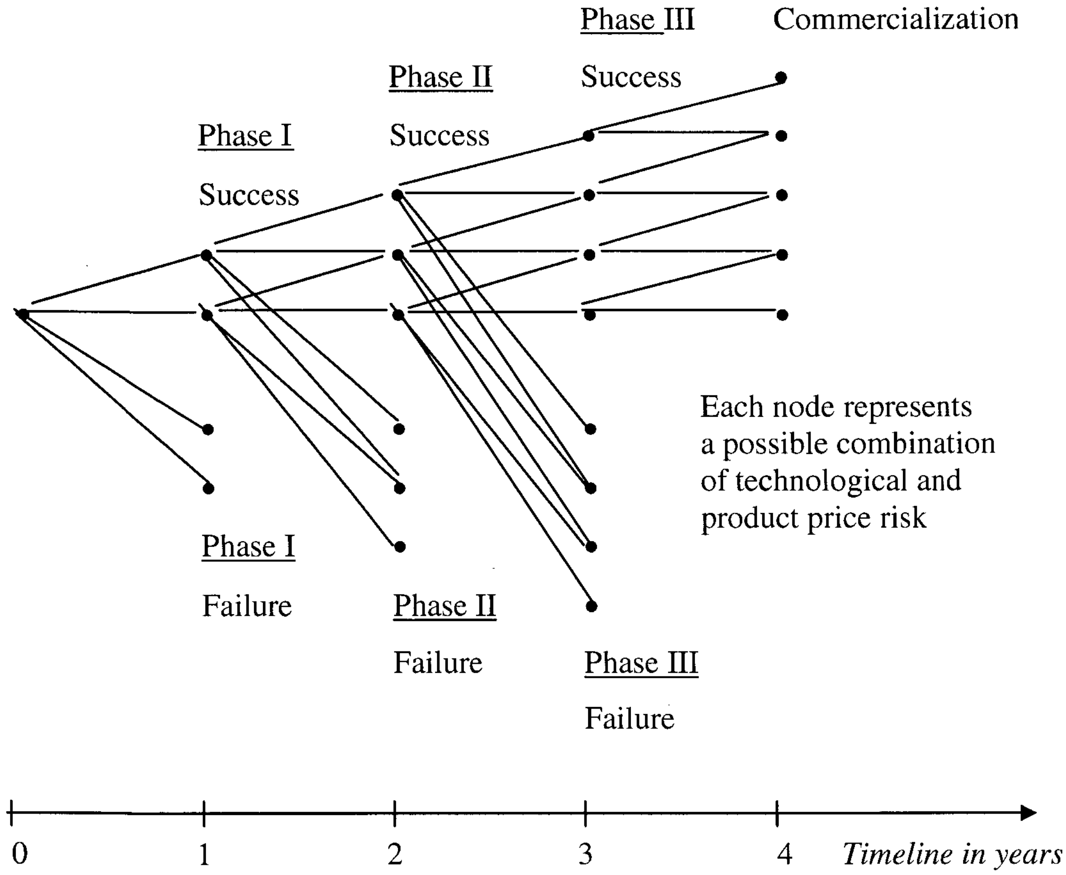
Modeling Risks:

To model the risks, we start by first determining how technological risk evloves through time. An event tree depicting this is the same as presented in the top section of Figure 3.2.

The volatility associated with the price of $4 per acre of land is 10 percent. This translates into annual up and down movements of 1.1052 and 0.9048 respectively using equation (2.10). These up (u) and down (d) movement parameters are then used to estimate the possible future prices. Table 3.5 illustrates how price risk evolves through time starting with the price of $4.

The two risks are jointly modeled by means of an event tree. This is presented by Figure 3.4.

Figure 3.4 Quadranomial event tree for the two risks



Source: Copeland and Antikarov, (2003: pp. 329).

Due to the assumption of independence equation (3.10) is used to determine the quadranomial risk neutral probabilities specific to each stage of the innovation chain. These are reported in Table 3.6.

Calculation of Base Case NPV:

To calculate the base case NPV we start by calculating the gross present value of the project if commercialized. This is first done by estimating the free cash flows at the end of each node in the commercialization phase. Using the top price of \$5.97 in Table 3.5, the estimated free cash flow at the top node in Table 3.7 is given by [(\$5.97 - \$1.5) × 1.6 million – \$1 million] × 7 = \$43.03 million. These cash flows are only realized when the product development process is successful. In the event that the new variety is denied approval its value will go all the way down to zero (Table 3.7). Subsequent to the estimation of the free cash flows, the certainty equivalent cash flows of the project are calculated by working backwards using the risk-neutral probabilities estimated at each node. These estimated certainty equivalent cash flows are then discounted at the risk free rate. The cash flow values obtained at the end of phase III are affected by only product price risk because all technological risk was resolved by the end of that phase of the product development process. Thus we have only two branches from each phase III node (Figure 3.4).

Since the price grows at the risk free rate in this model, equation (3.5) is used to calculate the risk-neutral probability. This is reported in Table 3.6. The cash flows at each node in phase III are estimated working backwards using the formula:

$$\frac{p \times up\ free\ cash\ flow + (1-p) \times down\ free\ cash\ cash}{1+r_f}; \qquad (3.12)$$

where p (i.e.0.73) represents the probability of the price moving up and $1-p$ (i.e.0.27) represents the probability of the price moving down. As an illustration, the value at the top node in phase III given successful commercialization as shown in Table 3.7 is given by: $\frac{(0.73 \times \$43.03m) + (0.27 \times \$30.92m)}{1+0.05} = \$37.88\ million$

The cash flow values in phase II are affected by two sources of risk that are independent of each other thus we have a quadranomial tree. The four estimated risk-neutral probabilities reported in Table 3.6 are used to calculate the certainty-equivalent cash flow values at each node in phases II. For example, the value at the top node in phase II (Table 3.7) is calculated by multiplying the payoffs by the risk-neutral probabilities estimated using phase III technological risk and price risk and discounted at the risk free rate. This is expressed as:

$$\frac{(0.6205\times\$37.88)+(0.2295\times\$26.90)+(0.1095\times\$0)+(0.0405\times\$0)}{1+0.05}=\$28.27\,million$$

The same procedure is used to calculate the certainty-equivalent cash flows in phase I. The present values of all the cash flows determined at each node of the project value tree are presented in Table 3.7. From this table the overall gross present value of the project is $12.15 million.

Having determined the gross present value of the project the next step is to calculate the present value of the investment. The investment costs at the various stages represent the exercise prices of call options and because these costs are assumed to be independent of the economy they are discounted at the risk free rate. The present value of the investment is therefore determined as follows:

$$PV\,(I)=\frac{\$2m}{(1.05)^0}+\frac{\$5m}{(1.05)^1}+\frac{\$6m}{(1.05)^2}+\frac{\$7m}{(1.05)^3}=\$18.25\ million$$

Thus the base case NPV of the project (i.e. without flexibility) is given by $12.15 million - $18.25 million = - $6.10 million. By the NPV criterion this project is not worth investing in since its NPV value is negative.

Calculation of Real Option Value:

The option to abandon and the option to invest are considered in the real option analysis. The estimation of the free cash flows following commercialization is the same as described above. Subsequently the backward calculation formula is used to determine the option values all the way to the root node. That is moving back from one node into the previous one, an investor determines whether to exercise the option (i.e. invest in the next stage) or abandon until the value of the option is obtained at time t=0. The option value is calculated by taking the maximum of the net investment or zero whichever is greater. Because all technological risk was resolved by the end of phase III of the product development process the risk-neutral probability estimated using only product price risk is used to calculate the option values at the end of phase III. As an illustration the option value at the top node in phase III (Table 3.8) is given by:

$$MAX\left(\left(\frac{(0.73 \times \$43.03) + (0.27 \times \$30.92)}{1 + 0.05}\right) - \$7\right) = \$30.88\ million$$

From phase II backwards to the root node, the quadranomial risk-neutral probabilities are used to estimate the option values. For example the option value at the top node in phase II is calculated by multiplying the payoffs by the risk-neutral probabilities estimated using phase III technological risk and price risk and discounted at the risk free rate:

$$MAX\left(\left(\frac{(0.6205 \times \$30.88) + (0.2295 \times \$19.90) + (0.1095 \times \$0) + (0.0405 \times \$0)}{1 + 0.05}\right) - \$6,\ 0\right) = \$16.6m$$

The real option payoff values as well as the investment strategy associated with the payoff value are presented in Table 3.8. The real option value of the project is $2.73 million thus the decision would be to go ahead and invest the initial $2 million in order to start phase I of the product development process. This implies that the value of managerial flexibility of this project is $0.73 million (i.e. $2.73 million - $2 million).

3.5 Summary of Valuation Results

The results obtained from the NPV, option to wait and compound sequential option analysis above indicate that when managerial flexibility is not included in the valuation framework the value of the project is underestimated. The NPV values are negative thus there is no justification for investing in the projects. When flexibilty is incorporated into the analysis the value of the projects became positive thus making the projects viable. The wait option value estimated indicates that the project may be worth more sometime in the next five years as compared to a negative value if executed immediately.

The binomial valuation framework used to evaluate the case examples incorporates flexibility as well as the option to abandon the project midstream if new information is unfavorable. Thus the case examples are very relevant to this thesis. The investment costs associated with the canola project is not incurred as a single up-front outlay but rather as a series of outlays over time. Therefore it can be valued as a sequential option. More importantly, the canola project described in chapter 4 is faced with two major risks. Since the quadranomial approach allows the major risks to be resolved simultaneously it is used as a working model to evaluate the canola R&D case study.

3.6 Tables for Chapter 3

Table 3.1 Calculation of Gross Present Value ($000)

Years	1	2	3	4	5	6	7	8	9	10
Expected Revenue	$0	$0	$3,012	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000
Expected Variable Cost	$850	$850	$850	$850	$850	$850	$850	$850	$850	$850
Total Fixed Cost	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400
Net free cash flows	-$1,250	-$1,250	$1,762	$1,750	$1,750	$1,750	$1,750	$1,750	$1,750	$1,750
Present value (P.V)	-$1,106	-$979	$1,221	$1,073	$950	$841	$744	$658	$583	$516
Gross present value	$4,500									

Table 3.2 Calculation of Present Value of Investment Cost

Years	0	1	2
Investment Cost (I)	$1,000,000	$3,700,000	$300,000
P.V of (I)	$1,000,000	$3,274,336	$234,944
Overall P.V of I	$4,509,280		

Table 3.3 Wait Option Associated with the Biotechnology R&D Project -Example 1

Years	0	1	2	3	4	5
Total Project Value (V)	$4,500,000	$5,778,114	$7,419,246	$9,526,500	$12,232,268	$15,706,543
		$3,504,604	$4,500,000	$5,778,114	$7,419,246	$9,526,500
			$2,729,388	$3,504,604	$4,500,000	$5,778,114
				$2,125,649	$2,729,388	$3,504,604
					$1,655,457	$2,125,649
						$1,289,272
Wait option payoffs	$703,775	$1,349,679	$2,516,619	$4,526,500	$7,232,268	$10,706,543
		$264,929	$563,957	$1,180,840	$2,419,246	$4,526,500
			$56,208	$134,962	$324,062	$778,114
				$0	$0	$0
					$0	$0
						$0
Investment Policy						
Time	**0**	**1**	**2**	**3**	**4**	**5**
0	Wait	Wait	Wait	Invest	Invest	Invest
1		Wait	Wait	Wait	Invest	Invest
2			Wait	Wait	Wait	Invest
3				Abandon	Abandon	Abandon
4					Abandon	Abandon
5						Abandon

Table 3.4 Agricultural R&D Project – Example 2

Years	0	1	2	3
Total Project Value (V)	$4,500,000	$5,778,114	$7,419,246	$9,526,500
		$3,504,604	$4,500,000	$5,778,114
			$2,729,388	$3,504,604
				$2,125,649
Commercialization option payoffs	$1,394,655	$2,077,392	$3,419,246	$5,526,500
(with abandonment value)		$990,133	$1,221,815	$1,778,114
			$900,000	$900,000
				$900,000
Basic R&D option payoffs	**$448,702**	$1,077,392		
	↑ This is PV of project	$0		

Investment policy associated with commercialization payoff values

Time		0	1	2	3
	0	Wait	Wait	Invest	Invest
	1		Wait	Wait	Invest
	2			Abandon	Abandon
	3				Abandon

Investment policy associated with basic R&D payoff values

Time		**0**	**1**
	0	Wait	Invest
	1		Abandon

Table 3.5 Evolution of Price Risk through Time – Example 3

		phase I	phase II	phase III	commercialization
Years	**0**	**1**	**2**	**3**	**4**
	$4.00	$4.42	$4.89	$5.40	$5.97
		$3.62	$4.00	$4.42	$4.89
			$3.27	$3.62	$4.00
				$2.96	$3.27
					$2.68

Table 3.6 Base Case Input Variables of the Quadranomial Model – Example 3

Up move parameter	1.1052
Down move parameter	0.9048
Risk neutral probability of price moving up	0.73

R&D Phase	Technological risks	Price Risk: Prob. up = **0.73**	Prob Down =**0.27**
Phase III	Prob. Success = **0.85**	0.6205	0.2295
	Prob. Failure = **0.15**	0.1095	0.0405
Phase II	Prob. Success = **0.75**	0.5475	0.2025
	Prob. Failure = **0.25**	0.1825	0.0675
Phase I	Prob. Success = **0.75**	0.5475	0.2025
	Prob. Failure = **0.25**	0.1825	0.0675

N.B: Technological risks × Price risk = Quadranomial risks in boxes

Prob = Probability of

Table 3.7 Project's Value Tree – Example 3

		phase I	phase II	phase III	commercialization	
Years	**0**	**1**	**2**	**3**	**4**	
	$12.15	$18.56	$28.27	$37.88	$43.03	**Success**
		$12.82	$19.82	$26.90	$30.92	
			$12.90	$17.92	$21.00	
				$10.56	$12.88	
					$6.23	
		$0.00	$0.00	$0.00	$0.00	**Failure**
		$0.00	$0.00	$0.00	$0.00	
			$0.00	$0.00	$0.00	
				$0.00	$0.00	
					$0.00	

- Year 4 values are free cash flows following commercialization
- Certainty equivalent cash flows in year 3 are estimated using the risk-neutral probability of the price moving up or down (i.e. price risk) reported in Table 3.6.
- Certainty equivalent cash flows in year 2 are estimated using the quadranomial probabilities determined by multiplying phase III technological risk and price risk (Table 3.6, top box).
- Certainty equivalent cash flows in year 1 are estimated using the quadranomial probabilities determined by multiplying phase II technological risk and price risk (Table 3.6, middle box).
- Certainty equivalent cash flows in year 0 are estimated using the quadranomial probabilities determined by multiplying phase I technological risk and price risk (Table 3.6, bottom box).

Table 3.8 Real Option Payoff Values and Investment Strategy – Example 3

			phase I	phase II	phase III	product launch	
	years	**0**	**1**	**2**	**3**	**4**	
RO value		$2.73	$5.23	$16.60	$30.88	$43.03	**Success**
			$0.00	$8.15	$19.90	$30.92	
				$1.23	$10.92	$21.00	
					$3.56	$12.88	
						$6.23	
			$0.00	$0.00	$0.00	$0.00	**Failure**
			$0.00	$0.00	$0.00	$0.00	
				$0.00	$0.00	$0.00	
					$0.00	$0.00	
						$0.00	
Investment policy		invest (I)	Invest (II)	Invest (III)	Invest (mkt)	Market	**Success**
			Abandon	Invest (III)	Invest (mkt)	Market	
				Invest (III)	Invest (mkt)	Market	
					Invest (mkt)	Market	
						Abandon	
			Abandon	Abandon	Abandon	Abandon	**Failure**
			Abandon	Abandon	Abandon	Abandon	
				Abandon	Abandon	Abandon	
					Abandon	Abandon	
						Abandon	

CHAPTER 4 THE CANOLA R&D CASE STUDY

This chapter addresses the canola meal enhancing R&D case study. It starts by providing a brief review of the agricultural biotechnology product development process in general. This review focuses on the number of stages in the product development process as well as some of the key activities done in each stage. Next, it provides a description of the case study. Afterward, PBI's canola R&D project and how that compares with the general biotechnology R&D process is explained. Subsequently, the possible real options inherent in the canola R&D project as well as the overall timeline associated with this project are discussed. The chapter concludes with a discussion on the data as well as assumptions used for evaluating the project.

4.1 Agricultural Biotechnology Product Development Process

Bringing a new agricultural biotechnology product to market is a difficult process involving many complex decisions. According to Zilberman et al, (1997) agricultural biotech products can be thought of as the result of a linear five-stage process: (1) research, (2) development, (3) testing and registration, (4) production and (5) marketing. These stages result in three major outputs. Research leads to the production of new knowledge about genetic manipulation techniques or the properties of a genetic sequence. By obtaining a patent, intellectual property rights are established, and users must acquire the rights to use the discovery. Development leads to a product or process that has clear commercial potential, which is then retained in-house or sold to a third party for testing and regulatory approval before moving finally into commercialization.

As pointed out by Zilberman et al, (1997) five main economic agents are involved in the product development process. These are:

1. Universities - conducts research that leads to important discoveries.
2. Small biotechnology firms made up of researchers and supported by venture capitalists, which tend to concentrate on developing biotechnology products, often combining efforts and resources through alliances with pharmaceuticals, other biotech firms, and academic researchers.

3. Large companies which, in addition to internal R&D capabilities and alliances with biotech firms, have strong marketing networks in place and enough financial resources to bear the costs of product registration.
4. Government which supports research at the universities, and regulates biotechnology-related activities.
5. Buyers or farmers.

McElroy, (2004) proposed a nomenclature that consist of: (1) discovery, (2) crop transformation, (3) field efficacy, (4) regulatory and (5) commercialization stage as what the agricultural biotechnology industry should consider in describing the plant product development cycle. The discovery stage begins with a product concept definition, and/or scientific innovation and ends with a proof of the trait or technology's effectiveness in a transgenic model plant system. Discovery also includes the detection of a target, trait or technology. It also includes the evaluation and improvement of a lead target, trait or technology. Furthermore, discovery includes the preliminary evaluation of the effectiveness of the trait or technology in an appropriate model plant system (McElroy, 2003). The crop transformation stage starts with the initial transformation of the target crop or plant production system under non production green-house or test field conditions. It ends with an initial demonstration of the functional effectiveness as well as the desired phenotypic effects of the particular trait being investigated. The field efficacy stage starts with the trait's functional effectiveness and the desired phenotypic effects of the model plant under non production green-house or test field conditions. It ends with the selection of the final transgenic material which has undergone field testing in environments similar to where they will eventually be grown in. The regulatory stage involves filling regulatory applications and obtaining regulatory approval for the sale of products in major market(s). In the commercial stage, the infrastructure necessary for the generation of the supply of the approved transgenic trait or technology is put into place. The commercial stage ends with substantial product sales.

Due to the fact that the product development process of biotechnology projects are divided into several stages, each stage can be thought of as an option to receive the next investment stage. The subsequent stages of a project are thus dependent on the success of prior stages. Since the different stages give options on other options the product development process can be thought of as compound options.

Associated with biotechnology R&D projects is a combination of both technical and economic risks (Dixit and Pindyck, 1994). The technical risk arises from the success or failure at the different stages of the product development process. Economic risk, on the other hand, arises from the uncertain future cash flows, which in turn depends upon the uncertain future demand of the product.

4.2 Case Study Description

The National Research Council - Plant Biotechnology Institute (PBI) is used as a case study to demonstrate how real options approach is used to analyze agricultural biotechnology R&D investment decisions. The institute focuses on basic research in three broad themes namely strategic technologies, modifying plants for increased value and improving plant performance (NRC-CNRC Plant Biotechnology Bulletin). To be able to provide cutting-edge research, the institute makes use of naturally formed research groups or teams. In 2004, the institute had five main research groups whose work focused on cell technologies, lipid biotechnology, molecular and developmental genetics, plant natural products and protein research respectively (NRC-CNRC Plant Biotechnology Bulletin). According to PBI every research programme goes through a three-year review process and evaluation is done using provisions stated in the organization's five-year strategic plan (Hinther, 2004)[9].

Research into canola is one of the main activities of PBI. Canola (i.e. improved rapeseed) has low levels of erucic acid (less than 2 per cent) in the oil portion and low levels of glucosinolates (less than 30 μmol/g) in the meal portion. The name canola was adopted in order to distinguish it from the original rapeseed varieties which contain high amounts of erucic acid and glucosinolates (Hickling, 2001).

The PBI canola research project evaluated in this thesis aims at improving the functional and nutritional composition of canola meal and oil products (Selvaraj 2002, Georges 2002) and thereby open up new markets in the pork, poultry and aquaculture

[9] Personal communication: July 26, 2004

industry (NRC-CNRC Plant Biotechnology Bulletin). Specifically the technology involves the reduction of anti-nutritional components such as sinapine and phytate in canola meal, using metabolic shunting or pathway modification via genetic engineering. Canola meal is a by-product of the oil crushing industry and as an oilseed meal it is similar to soybean meal, linseed meal and other oilseed meals. The anti-nutritional factors (ANF) reduce the nutritive value of canola meal when included in poultry, aquaculture and livestock feeds (Hickling, 2001). According to Manitoba Agriculture, Food and Rural Initiatives, (1999) feed costs in broiler chicken production in Canada are over 50% of operating costs. Soybean meal is commonly used in poultry rations. The canola meal currently produced in Western Canada has an economic value approximately 55% to 65% of soybean meal in broiler grower rations (Hickling, 2001). Internationally, feed costs represent 50% of production costs in salmon aquaculture (Bjorndal and Aarland, 1999; Asche, Guttormsen and Tveteras, 1999). A major feed input in aquaculture is fishmeal and the price of this protein supplement is expected to increase for a number of reasons (FAO, 2002)[10]. Aquaculture had gross revenue of $396 (US) and $714 (US) millions in Canada and the United States respectively in 2002 (FAO). Worldwide, aquaculture production was valued at $59 billion in 2002 and production is expected to grow (FAO, 2002). Substituting higher amounts of plant based proteins for fishmeal in aqua culture represents an emerging market opportunity for reduced ANF canola. Canada produces 5 to 8 million tonnes of canola each year. Approximately 60% of this production would be canola meal. That is 3 to 4.8 millions tonnes of canola meal.

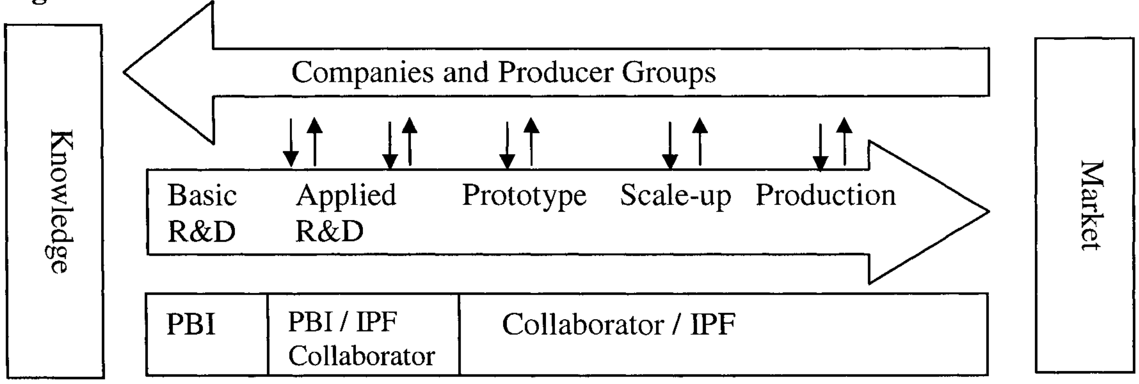
4.3 PBI's Canola R&D Process

PBI's business model is similar to the R&D timelines discussed in Zilberman et al, (1997) and McElroy, (2004). The business model of PBI is presented in Figure 4.1. Table 4.1 shows how PBI's R&D timeline compares with that of Zilberman et al, (1997) and McElroy, (2004).The development of the new canola variety by PBI is expected to go through five distinct stages. These are: (1) basic R&D, (2) applied R&D, (3)

[10] The future availability of fish meal is both uncertain and unstable. Global supplies of fish meal have peaked and show no sign of increasing.

prototype, (4) scale-up and (5) production. A brief summary of the expected research activities to be done in each stage of PBI's innovation chain are as follows:

Figure 4.1 PBI's Business Model



Source: Hinther, R. (2003). Presentation to Intellectual Property Management Workshop.

IPF = Industry Partnership Facility.

Basic R&D

In this stage the researchers start with already existing knowledge regarding identified genes of canola seeds and apply the technique of metabolic shunting to develop canola varieties with low levels of sinapine and phytate. Reports indicate that about 45-50% reduction of these anti-nutritional compounds have been achieved currently. The basic R&D stage takes approximately 4 years.

Applied R&D

For the technology to move further down the innovation chain, the business model of the institute stipulates that a collaborating firm must be identified. This firm must have a strong interest to take the technology all the way to commercialization from the basic R&D stage. The institute at this stage of the innovation chain provides an Industry Partnership Facility (IPF) to the collaborator and through that facility shepherd the innovation up to the production stage where the product is sold on to farmers to enhance agricultural production and thereafter to the processors. The facility covers the salaries of staff as well as the day-to-day consumables of the firm. In this stage field trials are conducted to determine the expression levels of the traits in the developed varieties. Trials in the applied R&D stage take about 4 years.

Prototype Stage

In this stage field trials are conducted to ascertain the impact of environmental conditions on the stability of the developed varieties. Plant breeding activities in this stage are aimed at introducing commercial lines, which are pure. Regulatory activities are also carried out in this stage. The regulatory bodies include the Canadian Food Inspection Agency (CFIA) and the Canadian Grains Commission. For the developed variety to be approved, 2 years of Co-op trials are required.

Scale-up Stage

This stage involves the multiplication of the developed breeder seed or pedigree. Regulatory activities are also conducted and final approval is completed in this stage. This stage takes approximately 2 years.

Production Stage

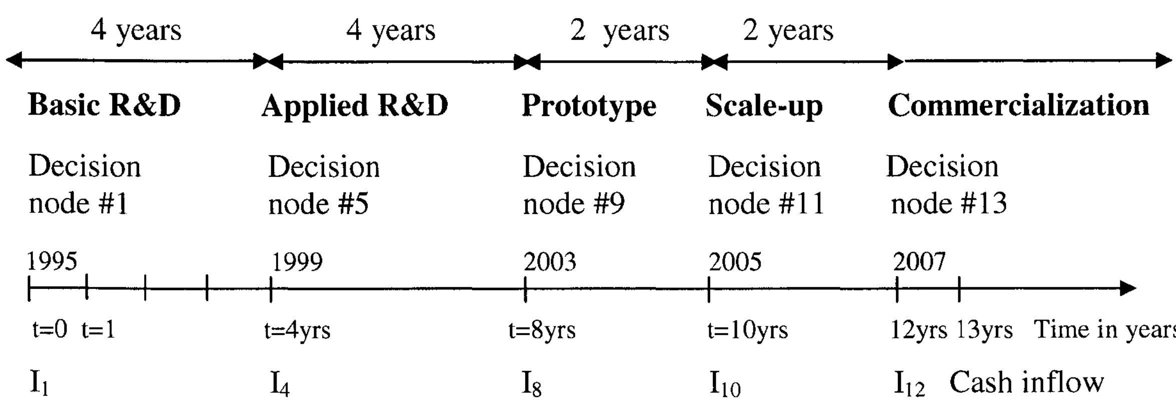
In this stage, the improved canola seed which has traits expressed in ultra-low glucosinolates canola lines is introduced into the market and the seeds are cultivated on farmers' field. This is the stage of the innovation chain where there is major cash inflow.

4.4 Real Options in the Canola R&D Project

According to Perlitz et al., (1999) the value of R&D investment is not primarily determined by the cash flows coming from the initial investment but by the future investment opportunities provided by the original investment. From the discussion of real options associated with project investment valuations in section 2.3, the relevant real options applicable to R&D projects include sequential options, option to abandon and growth options. Since most real options are often defined to have a long term maturity, it is quite possible that the investment project is stopped (option to abandon is exercised) before the expiration of the option. To consider the option to abandon, there should be the possibility of the canola R&D project being abandoned at some stage of the development process. This for example could occur through the outright sale of the rights to a different firm or licensing to another firm. Also for the growth option to be considered there should be a potential follow-on project from the current project.

With this in mind, a discussion was held with PBI. The compound sequential option model was identified as the most appropriate valuation model for estimating the value of this project. Valuing the project this way allowed us to model the subsequent follow-on investments in the R&D process as well as the optimal abandonment policy of PBI. To do this, PBI was assumed to exercise its call option on the next stage or make abandonment decision at the beginning of each year with the information acquired from the completion of the previous year's investment. Figure 4.2 show an overall timeline of the R&D process.

Figure 4.2 Overall Timeline of the Canola Meal Enhancing R&D Project



I_1 = Initial investment for basic R&D.

I_4 = Follow up investment for applied R&D.

I_8 = Follow up investment for prototype research.

I_{10} = Follow up investment for the scale-up stage.

I_{12} = Investment in production capacity required to commercialized the reduced ANF canola meal

Stage 1 comprises investment in basic R&D and it lasts for four years. This is valued as a series of four call options with an exercise price equal to the present value of the yearly basic R&D cost. Stage 2 comprises investment in applied R&D and it lasts for four years. Similarly, this is valued as a series of four call options with an exercise price equal to the present value of the yearly applied R&D cost. Stage 3 comprises investment in the prototype stage and this lasts for two years. Thus it is valued as a series of two call options with an exercise price equal to the present value of the yearly prototype cost. Stage 4 comprises investment in scale-up and this lasts for two years. This is also valued as a series of two call options with an exercise price equal to the present value of the yearly scale-up stage cost. Stage 5 comprises the investment associated with commercializing the reduced ANF canola meal. This is evaluated as call option with an exercise price equal to the present value of the commercialization cost. Thus, there are thirteen call options in a sequence.

For example, at time period (t=0) or decision node #1 in Figure 4.2 above, PBI decides whether to invest in the project based on the yearly expected costs incurred during the basic R&D, applied R&D, prototype, scale-up as well as the cost associated with commercializing the reduced ANF canola meal. At time period (t=1), the first option expires and therefore must be exercised at the first year cost of basic R&D or left unexercised at no cost. If exercised, the payoff is not directly dependent on the value of the underlying project but on the value given by the option to invest in the second year of basic research. Also at time period (t=2), the second option expires and therefore must be exercised at the second year cost of basic R&D or left unexercised at no cost. If exercised, the payoff is dependent on the value given by the option to invest in the third year of basic R&D. At time period (t=3), the third option expires and therefore must be exercised at the third year cost of basic R&D or left unexercised at no cost. If exercised, the payoff is dependent on the value given by the option to invest in the fourth year of basic R&D. At time period (t=4), the fourth option expires and therefore must be exercised at the fourth year cost of basic R&D or left unexercised at no cost. If exercised, the payoff is dependent on the value given by the option to invest in the first year of applied R&D. The same procedure is used in evaluating the remaining call options.

4.5 Project Data Requirements for NPV and Real Options Analysis

To value the canola meal enhancing R&D investment, data are required on the:

1. investment costs for basic R&D

2. investment costs for applied R&D
3. investment costs for prototype
4. investment costs for scale-up
5. investment costs for commercialization
6. price of the reduced ANF canola meal
7. market share of the reduced ANF canola meal after commercialization
8. other costs associated with producing the reduced ANF canola meal
9. key risks that affects the value of the project.

It is envisaged that the reduced ANF canola meal would be directly substitutable with soybean meal. Since it does not make economic sense to invest in the production of reduced ANF canola meal if its price would be lower than the unreduced or regular canola meal, it implies that the difference between the expected price of reduced ANF canola meal and that of the regular canola meal is what PBI or any potential investor is targeting. The value of this R&D project estimated is based on the difference between the two meal prices. This section gives an overview of the source of data as well as the assumptions used in determining the other input variables of the model where data are not available.

4.5.1 Data / Assumptions used to obtain Investment Cost Estimates

Basic R&D Investment Cost

The cost of undertaking basic R&D as well as the actual time the expenditures were incurred was obtained from the management of PBI. The expenditures received from PBI were aggregated and assumed to be invested equally over the four year basic R&D period. The yearly expenditure for basic R&D used in the analysis is $743,010. Details on the breakdown of the investment cost received from PBI are not presented due to confidentiality reasons.

Applied R&D, Prototype and Scale-up Investment Costs

Since PBI is a public research institute undertaking basic research, MCN BioProducts Inc. of Saskatoon is used as a proxy to estimate the investment cost for applied R&D, and the remaining stages of the R&D pipeline. MCN is an agricultural biotechnology company focused on the commercialization of a technology with a similar canola meal outcome. It is funded by Foragen Technologies Management Inc. (the first known seed investment fund that exclusively focuses on early stage advanced agricultural technology investments in Canada). In recognition of the need to respect confidentiality this analysis uses information in the public domain about MCN BioProducts Inc. and Foragen Technologies Management Inc.

Foragen invested CAN $1,000,000 as initial seed capital in MCN to move the technology from applied R&D through to commercialization (Foragen Visions, 2005). Foragen by this investment acquired a 50% share in MCN but this share will eventually decline to about 20% through subsequent financing. Also, Foragen provides management expertise as well as help source additional funds as MCN takes the innovation down the R&D pipeline.

It is assumed that a total of CAN $500,000 is invested on a yearly basis during the applied R&D stage. In consultation with PBI, the project management said that the yearly applied R&D costs could range from $350,000 to $500,000 thus suggested that sensitivity analysis should be carried out on the project using this range. Also $500,000 is assumed to be invested on yearly basis during the prototype and scale-up stages. These assumed investment costs were discussed with the management of PBI and were determined to be realistic.

Commercialization Investment Cost

Estimating the cost associated with commercialization was difficult due to lack of data. The analysis used the post approval pretax cost for commercializing pharmaceutical R&D output as a proxy (Kellogg and Charnes 2000). A total of $1,949,215 is used as the investment cost associated with product launch. The investment costs used in the analysis are presented in Table 4.2.

4.5.2 Data / Assumptions used to obtain Revenue Estimates

Price of Reduced ANF Canola Meal

Historical yearly soybean meal prices over the period 1986 to 2001 in US dollars per metric tonne are obtained from Statistics Canada. These prices are used as a proxy to determine the upper bound on the price of the reduced ANF canola meal required for estimating the cash flows from the technology once it is commercialized. The assumption here is that soy bean meal and reduced ANF canola meal are perfect substitutes. First, the soy bean meal prices are converted to Canadian dollars using annual exchange rates data obtained from CANSIM over the same period. The soybean meal prices in Canadian dollars are then deflated to 2001 prices using the Canadian consumer price index for all items from CANSIM. Subsequently an average of these prices over the period 1995 to 2001 is calculated. The soybean meal prices used are based on 48% crude protein content. According to the trading rules for canola meal in Canada and US, the minimum protein level should be 34% (COPA, 1999). Therefore simple proportion is used to adjust the estimated average price of soybean meal to reflect the minimum crude protein level of canola meal. The estimated adjusted price per metric tonne of reduced ANF canola meal used in the analysis is $208. This price is used as the upper bound price. The procedure for adjusting this price to reflect the minimum crude protein level of canola meal is presented in Appendix A. The data on soybean meal prices, annual foreign exchange rates in Canadian dollars and the all-items consumer price indexes (CPI) for Canada are presented in Table 4.3.

Price of Regular Canola Meal

Historical yearly canola meal prices over the period 1986 to 2001 in Canadian dollars per metric tonne are obtained from Statistics Canada. The canola meal prices are then deflated to 2001 prices using the Canadian consumer price index for all items from CANSIM. Subsequently an average of these prices over the period 1995 to 2001 is calculated. The estimated price of canola meal per metric tonne is $197. Canola meal contains at least 34% to about 40% of crude protein. The crude protein levels of the canola meal prices used were not specified in the data. Thus it is very difficult to use the estimated price of $197 as a basis for comparison in the analysis. Also, the estimated canola meal price is high as compared with the price Manitoba Agriculture reported in 2001. This is because the average regular canola meal price containing 34% crude protein reported by Manitoba Agriculture in 2001 is $160. This price of $160 reported by Manitoba Agriculture is chosen because the minimum crude protein content is used as a basis to adjust the meal value in the analysis. The data on canola meal prices and the all-items consumer price indexes (CPI) for Canada are presented in Table 4.3.

Sales Volume of Canola Meal (Market Size)

The market potential for MCN's products as stated in their website is projected to be in excess of 225,000 metric tonnes of canola meal per year. The average annual total canola meal produced from canola grown in Canada over the period 1995 to 2001 is 3,990,310 metric tones (Statistics Canada, 2005). This average annual estimate is used as a proxy of the total market volume available to the Canadian canola industry and it includes all the meal produced from seeds exported and crushed outside Canada. Using this average annual estimate, MCN market share projection represents 6% of the market for canola meal. This per cent market share is based on the assumption that all the regular canola seeds harvested in Canada are crushed domestically. In comparison to the actual average canola meal produced in Canada over the period 1992 to 2003 obtained from Statistics Canada, this volume represents 13%. Data on historical canola production in Canada over the period 1986 to 2001 are presented in Table 4.4. Data on the actual canola meal produced in Canada is presented in Table 4.5. The canola meal market encompasses livestock, poultry and aquaculture industries.

Given successful commercialization and the fact that the canola meal enhancing technology is a platform technology, it can potentially replace the conventional canola varieties grown in Western Canada. However this can occur overtime and not immediately. As a result the MCN market size volume (i.e. 225,000 tonnes) is chosen and used in the analysis. Sensitivity analysis is however done to determine the effect of the variation of this market volume on the value of the project.

The chosen canola meal sales volume translates to about 375,000 tonnes of canola seed i.e. $\left(225{,}000 \times \frac{1}{0.6} \quad or \quad 225{,}000 \times 1.666667 = 375{,}000\right)$. This is because 60% of the seed constitute the meal portion. According to Alberta Agriculture and Food and Rural Development, (2005) the five years average yield of Canadian canola over the period 2001 to 2005 is 1504 kg/ha (i.e. 27 bushels/acre). Using this yield estimate, the crop area in hectares, required to produce 225,000 tonnes of canola meal, is estimated as $\frac{375{,}000 \times 1000}{1504} = 249{,}335 \;\; ha$.

Potential Benefit

To estimate the potential benefit, it is assumed that there is no change in the yields of canola or oil quality when technology is fully commercialized. The price of reduced ANF canola meal is used as the upper bound price while that of regular canola meal reported by Manitoba agriculture is used as the lower bound price in the analysis. The difference in these two prices multiplied by the sales volume of the reduced ANF canola meal constitutes the benefit that PBI wants to capture given successful commercialization of the project. The analysis assumed that PBI is able to capture all this benefit (i.e. increased dollar value of the improved canola meal) once commercialized. This assumption is realistic from a public policy perspective. This is because the canola R&D project is a platform technology. The technology can be incorporated into all canola varieties in Western Canada if fully commercialized. The total benefit is a proxy for commercial benefit to the entire canola industry. The assumption that PBI is able to capture all this benefit however is not realistic from a private investor's perspective since no one firm can capture all the total benefit given successful commercialization of the project.

The benefit captured (i.e. total or private) should include the infinite cash flows (i.e. perpetuity) of the project once the technology is fully commercialized. The magnitude of these infinite cash flows is determined by the discount rate used. Lavoie, (2005) argued that traditional venture capitalist use between 20 and 30% discount rates to evaluate businesses with existing management, some level of sales and profitability. Also, in the view of Shepherd and Douglas, (1999) businesses with a successful track record, but who need capital to finance growth have significant risk of default and investors discount cash flows from those businesses by 15% - 30%. Since at the commercialization stage of the canola R&D project, all these criteria would have been met, 20% is chosen as the discount rate for calculating the perpetuity associated with the project. The discount rate of 20% used falls within the range of 15% - 30% proposed by Shepherd and Douglas, (1999).

A discount rate of 20% implies that once the canola meal enhancing technology is fully commercialized, its value is five times the estimated net cash flows. The perpetuity is estimated using equation (3.2). In consultation with PBI's project management, this rate was determined as realistic. The estimates used in determining the project's free cash flows following commercialization are presented in Table 4.6.

4.5.3 Data / Assumptions used to obtain other costs after Commercialization

Once the improved canola seed is launched, production and processing costs are incurred before the meal is finally produced. These costs must be captured in the analysis in order to correctly value the technology. An assumption is made to provide an estimate of these costs once the technology is fully commercialized.

The benefit PBI is targeting is assumed to be based on the price difference between the reduced ANF canola meal and the regular meal which is \$48. This value represents 23% of the price of the reduced ANF canola meal [i.e. $\left(\frac{\$48}{\$208}\right)\times 100\% = 23\%$]. This implies that the remaining 77% (or \$160) is assumed to be the other costs for producing the reduced ANF canola meal given successful commercialization. The procedure used to model these other costs such that the value of the project estimated is based on the price difference of \$48 is expressed as:

$$\$208-(\$208\times a)=\$48 \quad \Rightarrow \quad a=1-\left(\frac{\$48}{\$208}\right)=77\% \quad ; \quad 77\%\times\$208=\$160 \qquad (4.1)$$

These numbers were discussed with the management of PBI and were determined to be realistic. Modern agricultural biotechnology leads to the creation of supply chains involving identity preservation of genetically modified (GM) and non-GM crops. The cost required for maintaining an identity preserved system so as to prevent the improved canola meal from mixing with the conventional one is assumed to be part of these other cost. The cost for identity preservation vary depending on whether it is segregation which traces back to a particular producer or field or that which trace back to a particular grain elevator company.

According to Stuart and Phillips, (2001) discussions with various stakeholders in the canola industry in 1996 revealed that the cost of identity preserved production and marketing is C\$33-C\$41 per tonne. These costs are shared by the owners of the technology, farmers and the grain trade and processors who seek to increase their market share. Huygen et. al., (2003) provides identity preserved cost estimates for three selected supply chains systems for Canadian non-GM wheat at various levels of tolerance for GM material. Tolerance for non-GM is referred to as the maximum allowable GM content to still be considered as non-GM. From the highest tolerance level of 5% to the lowest tolerance level of 0.1%, the cost for managing identity preserved supply chains of wheat ranges from \$1.16 to \$7.88 per tonne.

4.5.4 Data / Assumptions used in Estimating Project Volatility

Similar to the case example in section 3.4 two key sources of risk namely technological and product or output price are identified to be associated with the canola R&D investment. These major risks are kept separate in order to model their interaction and effect on the project's value explicitly. Price risk is however assumed to be correlated with the canola and canola meal market.

According to PBI (Hinther, 2004) there is 30% chance that the technology will move from basic R&D to applied R&D stage. The probability of moving the technology from the applied R&D stage to prototype ranges between 50-60%. The probability of success from prototype to scale-up ranges between 70-75% and from scale-up to commercialization the probability of success ranges between 80-85%. The probability of success from one stage to the next refers to the technological risks associated with the project. The technological risks are completely resolved at the end of the scale-up stage.

The volatility associated with the price of reduced ANF canola meal is estimated using historical soybean meal price data over the period 1986 to 2001. The standard deviations of these prices were estimated based on the per cent changes of the natural logarithms of the deflated prices. Using equation (3.4), the estimated price volatility is 9%. Given this volatility, equation (2.10) is used to estimate the risk neutral probability of the price moving up or down (price risk). Table 4.7 shows the project risks used in the analysis.

The volatility associated with soybean meal price is similar to that of regular canola meal. The estimated volatility associated with the price of regular canola meal using historical canola meal price data over the period 1986 to 2001 (Table 4.3) is 8.7%.

4.5.5 Risk-free Rate of Return Data

Data on the auction yields rate of a one-year Treasury bill is used (Bank of Canada, 2005). The calculated five-year average auction yields rate (2000-2005) of a one-year Treasury bill in Canada is 3.5%. This rate is used as the risk-free rate in the analysis.

4.6 Tables for Chapter 4

Table 4.1 Comparison among PBI, Zilberman and McElroy R&D Timelines

Stage	PBI	Zilberman	McElroy
1.	Basic R&D	Research	Discovery
2.	Applied R&D	Development	Crop transformation
3.	Prototype	Testing and registration	Field efficacy
4.	Scale-up	Production	Regulatory
5.	Production	Marketing	Commercialization

Table 4.2 Investment Costs Associated with the R&D Process

Stage	Start Year	Cost / year	Number of years
Basic R&D	1995	$743,010	4
Applied R&D	1999	$500,000	4
Prototype	2003	$500,000	2
Scale-up	2005	$500,000	2
Commercialization	2007	$1,949,215	1

Table 4.3 Soybean / Canola Meal Nominal Prices, Annual Foreign Exchange Rates in Canadian Dollars and Consumer Price Indexes (CPI) for Canada, All Items.

Year	Soybean Meal Prices ($US/tonne)	Annual Foreign Exchange Rate	CPI	Canola Meal Prices (CDN.$/tonne)
1986	177.31	1.39	78.1	150.02
1987	239.35	1.33	81.5	150.66
1988	252.40	1.23	84.8	195.25
1989	186.48	1.18	89	176.01
1990	181.38	1.17	93.3	146.7
1991	189.21	1.15	98.5	137.87
1992	193.75	1.21	100	153.82
1993	192.86	1.29	101.8	169.7
1994	162.55	1.36	102	171.06
1995	235.92	1.38	104.2	157.4
1996	270.90	1.36	105.9	230.11
1997	185.28	1.39	107.6	233.3
1998	138.55	1.48	108.6	149.3
1999	167.70	1.49	110.5	145.62
2000	173.60	1.48	113.5	172.92
2001	167.70	1.55	116.4	210.24

Source: CANSIM

Table 4.4 Canadian Canola Seed / Canola Meal Production (000 Tonnes)

Year	Ontario	Manitoba	Saskatchewan	Alberta	British Columbia	Total Canada Canola Seed	Canola Meal**
1986	73.5	567	1,440.20	1,587.60	45.5	3,713.80	2228.28
1987	29.5	567	1,406.10	1,667.00	49.9	3,719.50	2231.7
1988	27.2	635	1,542.20	1,973.10	40.8	4,218.30	2530.98
1989	24.9	385.6	1,360.80	1,406.10	31.8	3,209.20	1925.52
1990	43.1	460.4	1,451.50	1,281.40	29.5	3,265.90	1959.54
1991	45.4	796.1	1,723.70	1,621.60	37.4	4,224.20	2534.52
1992	29.5	986.6	1,474.20	1,349.40	32.7	3,872.40	2323.44
1993	38.6	907.2	2,381.40	2,109.20	43.1	5,524.90	3314.94
1994	45.4	1,485.50	3,175.10	2,472.10	54.4	7,232.50	4339.5
1995	65.8	1,227.00	2,630.80	2,449.40	61.2	6,434.20	3860.52
1996	45.5	1,068.20	2,222.60	1,701.00	19.1	5,062.30	3037.38
1997	54.4	1,496.90	2,698.90	2,109.20	22.7	6,393.10	3835.86
1998	56.7	1,803.00	3,231.80	2,472.10	61.2	7,643.30	4585.98
1999	54.4	1,707.80	3,975.70	2,971.00	62.4	8,798.30	5278.98
2000	38.6	1,487.80	3,424.60	2,188.60	55.2	7,205.30	4323.18
2001	31.3	1,134.00	2,154.60	1,655.60	34.0	5,017.10	3010.26
Estimated average canola meal produced (1995 - 2001)							**3990.31**

Source: Field Crop Reporting Series - Statistics Canada

* **Calculated.** The values refer to the potential canola meal if all canola seed in Canada were crushed domestically. 60 % of canola seed = canola meal.

Table 4.5 Canadian Canola Meal Supply and Demand

Canadian Canola Meal Supply and Demand - updated December 31, 2003
Crop Year - August 1st to July 31st
Source: Statistics Canada - Cereals and Oilseeds Review & COPA Newsletter
(000 Tonnes)

	1992 -93	1993 -94	1994 - 95	1995 - 96	1996 - 97	1997 - 98	1998 - 99	1999 - 00	2000 - 01	2001 - 02	2002 - 03
Stocks	13	58	35	36	33	59	41	39	30	22	21
Production	1165	1340	1565	1724	1649	2004	1940	1858	1870	1427	1390
Imports	0.1	-	-	0.2	5	5	4	5	3	3	20
Total Supply	1208	1398	1600	1760.2	1687	2068	1985	1902	1903	1452	1431
Exports	759.1	932.6	1067.5	1214.7	1087.3	1419	1259	1139	1135.1	799.4	830.4
Domestic Utilization	391.0	430.4	496.5	545.4	543	610	687	744	746	632	576
Total Demand	1150	1363	1564	1727.2	1628	2027	1946	1872	1881	1431	1406
Ending Stocks	58.0	35	36	33	59	41	39	30	22	21	25
Actual average canola meal produced in Canada (1995 - 2001)											**1781.71**

Table 4.6 Estimates used in determining the Project's Free Cash Flows

Parmeter	Estimate
Sales volume of canola meal in metric tonne	225,000
Market share	6%
Price per metric tonne of reduced ANF canola meal	$208
Price per metric tonne of regular canola meal	$160
Discount rate	20%
Other costs associated with producing reduced ANF canola meal	77% of revenue

Table 4.7 Project Risks

Stage	Probability of Success (Technological risk)	Price volatility
Basic R&D	30%	-
Applied R&D	60%	-
Prototype	75%	-
Scale-up	85%	-
Commercialization	-	9%

CHAPTER 5 ANALYSIS, RESULTS AND DISCUSSSION

This chapter addresses the quantitative evaluation of the canola R&D project. The value of the project determined is based on traits expressed in ultra-low glucosinolates canola lines. Essentially a four-step valuation approach is used to value the canola meal enhancing R&D project. Step 1 involves modeling the key risks that drive the value of the project by means of event trees. Step 2 addresses the calculation of the base case NPV without flexibility. Step 3 involves incorporating managerial flexibilities into the analysis and finally step 4 addresses the calculation of the real option value.

The analysis is done by using models built in Microsoft Excel software. Four different scenarios of the same model are evaluated. Since the investment costs are staged, it is important to determine the value of the project at the beginning of each stage of the product development process. This would enable the firm commercializing the technology to determine whether it makes economic sense to continue to invest until the technology is fully commercialized. The core assumption for all these four scenarios are that 23% of the reduced ANF canola meal value given successful commercialization is captured (i.e. $48/tonne at base case price of $208 is captured). The descriptions of the four scenarios are as follows:

- Scenario 1 (Basic R&D) - PBI is assumed to take the innovation all the way to market launch. This scenario is chosen to determine the appropriate public investment policies for PBI. The Canola Council of Canada acknowledges that the future of the canola industry depends on innovation through research and development. However R&D funds are limited therefore must be allocated to projects that are deemed to be important. Thus, it is important for PBI to determine whether the overall project is feasible, otherwise no private firm will be interested in the technology.
- Scenario 2 (Applied R&D) - Investment in basic R&D is assumed to be sunk and a collaborating firm as stipulated by the business model of PBI is assumed to take the innovation from the applied R&D stage all the way to market launch. This scenario is chosen in order to estimate the value of the project at the start of the applied R&D stage. The results from this scenario will enable PBI to evaluate its investment policies.

- Scenario 3 (Prototype) - Evaluates the project at the prototype stage on the assumption that the investment costs associated with prior stages are sunk.
- Scenario 4 (Scale-up) - Evaluates the project at the scale-up stage on the assumption that the investment costs associated with prior stages are sunk.

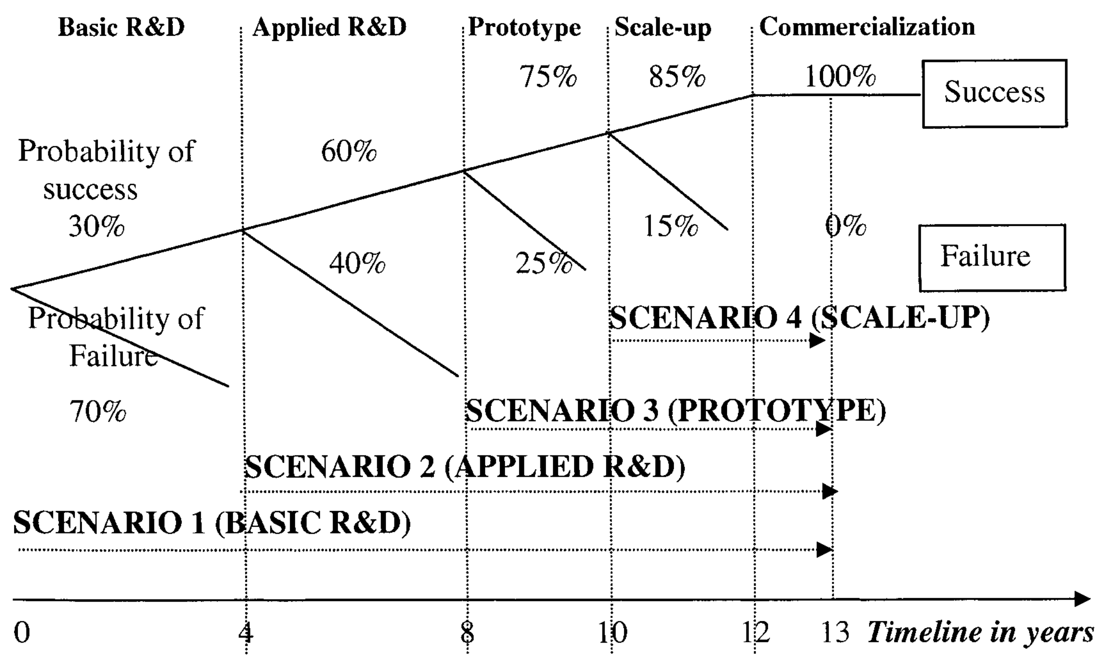
5.1 Modeling Risks

This section addresses how the risks - technological and product price are modeled. Technological and product price risks evolve simultaneously through time and are assumed to be uncorrelated with each other. Each of these risks is assumed to follow a geometric Brownian motion stochastic process thus the quadranomial approach is used to model the risks. The modeling procedure is similar to case example 3, developed in section 3.4. The input variables reported in Table 4.7 are used.

5.1.1 Modeling Technological Risks associated with the Canola R&D Stages

The probabilities of success and failure (technological risks) for each of the various stages during the product development process given by the project management are modeled using an event tree. Figure 5.1 illustrates how technological risks evolve through time.

Figure 5.1 Evolution of Canola Technological Risks through Time



Source: Table 4.7

5.1.2 Modeling Price Risk

The reduced ANF canola meal estimated price (i.e. $208) is used as the starting price to determine how price risk evolves through time. The estimated volatility associated with this price is 9%. Price risk is assumed to be correlated with the market and a multiplicative binomial lattice is developed. Equation (2.10) is used to calculate the up (u) and down (d) movement and the risk neutral probability. These are reported in Table 5.1. An event tree which illustrates the evolution of price risk through time starting with a price of $208 is presented in Table 5.2. The terminal prices at each end of the tree are then used to estimate the infinite free cash flows when the technology is fully commercialized.

5.1.3 Joint Modeling of Technological and Price Risks

The two risks are jointly modeled by means of an event tree similar to Figure 3.5. The technological risks for each stage are converted to annual risks since the risk associated with price is annual. As an illustration the yearly basic R&D probability of success (ρ_{yBRD}) given a cumulative probability of success for the basic R&D stage of 30% is given by: $(\rho_{yBRD})^4 = 0.3 \quad \Rightarrow \quad \rho_{yBRD} = (0.3)^{1/4} = 0.74$ Due to the assumption of independence equation (3.10) is used to determine the quadranomial risk-neutral probabilities specific to each stage of the innovation chain. The annual and quadranomial risk-neutral probabilities used in the analysis are presented in Table 5.1.

5.2 Calculation of Base Case NPV and Real Option Value

The procedure for calculating the base case NPV is similar to the case example discussed in section 3.4. The input variables reported in Tables 4.2 and 4.6 are used to calculate the value of the project. The NPV is calculated by subtracting the present value of the total investment cost from the gross present value of the project. To estimate the gross present value of the project, the free cash flows at the end of each node in the year the reduced ANF canola meal is commercialized is first determined. The certainty equivalent cash flows of the project are calculated by working backwards using the quadranomial risk-neutral probabilities reported in Table 5.1. These estimated certainty equivalent cash flows are then discounted at the risk free rate. Equation (3.2) is used to capture the value of perpetuity associated with the project once commercialized.

The option to abandon as well the compound option to invest is considered in the real option analysis. The abandon value is assumed to be zero. Since the research is ongoing the option to wait does not exist so PBI is faced with the decision to either continue to invest or abandon. ROV hereafter in this analysis refers to the estimated compound sequential option value. The procedure used is similar to what is used to calculate the ROV in section 3.4. To calculate the ROV of the project, the free cash flows at the end of each node in the year that the product is commercialized is first estimated. Since technological risk is completely resolved at the end of the scale-up stage, equation (3.12) is used to determine the vector of payoff values at the end of that stage. These values are affected by only price risk. The ROV of the project at the root node i.e. time period (t=0) is determined working backwards using equation (3.11). This is because the payoff values of the first year of the scale-up stage and all other values preceding that are affected by both risks. The ROV of the project estimated at the root node (t=0) refers to the real option value of the project. This value includes the investment cost required to proceed to the next stage of the canola R&D project. The decision criteria at time period t=0 is that, if the real option value is greater than the investment cost required to proceed to the next R&D stage, then, the decision would be to invest in the next stage of R&D, otherwise the project is abandoned. That is, if at t=0:

- ROV > investment cost required to proceed to the next stage of R&D → Invest
- ROV < investment cost required to proceed to the next stage of R&D → Abandon

When the investment cost required to proceed to the next R&D stage is subtracted from the estimated real option value of the project at time period t=0, what is left constitute the value of managerial flexibility associated with the research project.

5.2.1 Scenario 1 - Project's Base Case NPV and ROV at the Basic R&D Stage

In the basic R&D scenario the NPV and ROV of the entire R&D project is estimated. This scenario captures all the different stages of the product development process thus has a timeline of thirteen (13) years. The base case NPV and ROV given by the basic R&D scenario are denoted as NPV1 and ROV1 respectively.

Calculation of NPV1

The infinite free cash flows of the project once fully commercialized are first calculated. As an illustration, the procedure for estimating the infinite free cash flow at the top node in year 13 (see Table 5.3) is given by:

$$\frac{\$670 \times 225,000 - [(\$670 \times 225,000) \times 0.77]}{0.2} = \$173,987,603$$

These cash flow values are only realized when the product development process is successful. In the event that the product is denied approval its value will go all the way down to zero as there would be no sales (Table 5.3). Subsequently, the certainty equivalent cash flows of the project are calculated by working backwards using risk-neutral probabilities estimated at each node. The vector of cash flow values in year 12 and beyond are affected by only price risk thus equation (3.12) is used for the calculation. As an illustration, the value at the top node in year 12 (Table 5.3) is given by:

$$\frac{(0.68 \times \$173,987,602.5) + (0.32 \times \$145,326,661.5)}{1+0.035} = \$159,107,905$$

All other cash flow values from year 11 backward to the root node are affected by both risks. Thus, the stage specific quadranomial risk-neutral probabilities reported in Table 5.1 are used to calculate the certainty equivalent cash flows. For example, the value at the top node in year 11 (Table 5.3) is given by:

$$\frac{(0.62 \times 159,107,905) + (0.30 \times 132,898,093.4) + (0.05 \times 0) + (0.03 \times 0)}{1+0.035} = \$134,145,056.9$$

The present value of the cash flows determined at each node of the project value tree is presented in Table 5.3. From this table the overall gross present value of the project is $6,244,906.

Having determined the gross present value of the project the next step is to calculate the present value of the investment. These costs are assumed to be independent of the economy thus they are discounted at the risk free rate. The present value of the investment costs is presented in Table 5.4. From this table the present value of the total investment cost is $6,970,598.

The base case NPV of the project (i.e. without flexibility) at the beginning of the basic R&D stage is given by: \$6,244,905.9 - \$6,970,598 = -\$725,692. By the NPV criterion this project is not worth investing in since the NPV is negative.

Calculation of ROV1

The procedure for estimating the infinite free cash flows once the technology is commercialized is the same as explained in the determination of the base case NPV. Subsequent to the estimation of the infinite free cash flows, the real option model incorporates the option to invest or abandon the research project in the analysis. This is where the estimation procedure differs from the NPV model. In the event that there is a failure the value of the project at that node would be zero (see Table 5.5). Technological risk is resolved by the end of the scale-up stage (i.e. in year twelve), thus the vector of payoff values at the end of that stage are affected by only price risk. Using equation (3.12), the pay-off value at the top node in year 12 (see Table 5.5) is given by:

$$MAX\left(\left(\frac{(0.68\times\$173{,}987{,}602.5)+(0.32\times\$145{,}326{,}661.5)}{1+0.035}\right)-\$1{,}949{,}215\ ,\ 0\right)=\$157{,}158{,}690.5$$

All other cash flow values from year 11 backward to the root node are affected by both risks. Equation (3.11) is used to calculate the certainty equivalent cash flows of the project from year eleven (11) backwards to the root node. The quadranomial probabilities reported in Table 5.1 are used. For example, the pay-off value at the top node in year 11 is given by:

$$MAX\left(\left(\frac{(0.62\times157{,}158{,}690.5)+(0.30\times130{,}948{,}878.9)+(0.05\times0)+(0.03\times0)}{1+0.035}\right)-500{,}000,\ 0\right)=\$136{,}543{,}046.9$$

The real option payoff values determined at the various nodes of the value tree is presented in Table 5.5. From this table, the real option value at the beginning of the basic R&D stage (ROV1) obtained by valuing the project as a series of compound call options is \$5,407,598. This value is greater than the investment cost required to start the first year phase of basic R&D (i.e. \$743,010). Therefore the optimal decision would be to invest the initial \$743,010 and start with the first year phase of basic research. This implies that the value of managerial flexibility associated with the canola research project at the beginning of the basic R&D stage is \$4,664,588 (i.e. \$5,407,598 - \$743,010). In the event that that there is additional research that needs to be done to make the project viable (for example research on canola seed coat), the estimated value of managerial flexibility (i.e. $4,664,588) indicates the maximum amount of money PBI should invest in those additional research activities.

The real options approach, besides providing a methodology for valuing managerial flexibilities, also provides information on the investment strategy to follow. By examining the payoff values at each node an investor can determine whether it is optimal to continue to invest, or abandon the project midstream. The criteria used to determine the optimal investment policy given by this model is similar to equations (3.7) and (3.9). If the option value if exercised is greater than zero the optimal decision would be to exercise the option or invest in the next stage otherwise the project is abandoned at that point. The investment strategy associated with the real option payoff values are presented in Table 5.6. From this table, it is optimal to invest in the project.

The estimated NPV and ROV of the basic R&D scenario as well as the base assumption used during the estimation are presented in Table 5.7. In comparison to the results of the base case NPV, the real options approach increases the estimate of the project's value significantly i.e. from approximately -$725,692 to $5,407,598. Thus the investment strategy changes from abandon to invest in the project. Under the assumptions used, the real option analysis has shown that managerial flexibility has value thus any valuation model which ignores this flexibility is bound to underestimate or overestimate the project's value.

5.2.2 Scenario 2 - Project's Base Case NPV and ROV at the Applied R&D Stage

The same procedure outlined for calculating the NPV and ROV in section 5.2.1 is used. The value of the project is estimated from the applied R&D stage. The underlying assumption is that the investment in basic R&D by PBI is sunk and that an entirely new company takes the technology from the applied R&D stage through to product launch. PBI in the process receives royalty from the sales of the reduced ANF canola meal once commercialized however the modeling of the royalty due PBI is not included in the analysis. This allows the quantification of the entire value of the project after the completion of the basic R&D stage. The timeline in this analysis is therefore reduced to nine years. The base case NPV and ROV given by Scenario 2 (Applied R&D) are denoted as NPV2 and ROV2 respectively.

Calculation of NPV2

The present value of the cash flows determined at each node of the project value tree is presented in Table 5.8. From this table the overall gross present value of the project is $20,766,572. Similarly, the present value of the investment cost determined is presented in Table 5.9. From this table the present value of the total investment cost is $4,867,177. Therefore the base case NPV of the project for Scenario 2 (Applied R&D) is given by: $20,766,572 - $4,867,177 = $15,899,395.2. This positive NPV value implies that the project is viable. This result is not surprising. This is because the entire cost associated with basic research is treated as sunk costs.

Calculation of ROV2

The real option payoff values and its associated investment strategies determined are presented in Table 5.10. From this table the real option value at the beginning of the applied R&D stage (ROV2) obtained by valuing the project as a series of compound call options is $18,986,957. Since this value is greater than the investment cost required to start with the first year of applied research (i.e. $500,000), the optimal decision would be to invest the initial $500,000 and start the first year applied R&D phase. This implies that the value of managerial flexibility associated with the canola research project at the beginning of the applied R&D stage is $18,486,957 (i.e. $18,986,957 - $500,000).

NPV2 and ROV2 as well as the base assumption used during the estimation are presented in Table 5.7 By comparing NPV2 and ROV2 of the project, the results show that the real options approach increases the estimate of the project's value by 19%

5.2.3 Scenario 3 - Project's Base Case NPV and ROV at the Prototype Stage

Scenario 3 (Prototype) estimates the value of the project from the prototype stage to commercialization with the assumption that the investment costs in basic and applied R&D are sunk. The timeline in years is therefore reduced to five years. The base case NPV and ROV given by Scenario 3 (Prototype) are denoted as NPV3 and ROV3 respectively.

Calculation of NPV3

The present value of the cash flows determined at each node of the project value tree is presented in Table 5.11. From this table the overall gross present value of the project is $34,528,183.8. Similarly the present value of the investment cost is presented in Table 5.12. From this table the present value of the total investment cost is $3,477,726. The base case NPV of the project for Scenario 3 (Prototype) is given by: $34,528,183.8 - $3,477,726 = $31,050,457.8. As compared with NPV2, the value of the project without flexibility at the prototype stage has increased by about 95%. The value of the project at this point is not only high but positive implying that the project is viable.

Calculation of ROV3

The real option payoff values and its associated investment strategies estimated are presented in Table 5.13. From this table the real option value (ROV3) at the beginning of the prototype stage obtained by valuing the project as a series of compound call options is $32,365,041. This real option value is greater than the initial investment cost required to proceed with the first year prototype stage research (i.e. $500,000). Therefore the optimal decision would be to invest the initial $500,000 and start with the first year prototype stage research. This implies that the value of managerial flexibility associated with the canola research project at the beginning of the prototype stage is $31,865,041 (i.e. $32,365,041 - $500,000). In comparison with NPV3, the real option analysis increases the estimate of the value of the project by only 4%. This by inference implies that as the risk surrounding a particular project is reduced to the barest minimum the value of managerial flexibility declines accordingly.

5.2.4 Scenario 4 - Project's Base Case NPV and ROV at the Scale-up Stage

Scenario 4 (Scale-up) estimates the value of the project from the scale-up stage to commercialization. Since investment costs in the prior stages are assumed to be sunk the timeline in years is reduced to three years. At this point the risks surrounding the technology is reduced significantly thus the a priori expectation is that the ROV of the project would not be too different from the NPV. The base case NPV and ROV given by Scenario 4 (Scale-up) are denoted as NPV4 and ROV4 respectively.

Calculation of NPV4

The present value of the cash flows determined at each node of the project value tree is presented in Table 5.14. The overall gross present value of the project is \$45,982,497.6. Also, the present value of the investment is presented in Table 5.15. From this table the present value of the total investment cost is \$2,707,927. Thus the base case NPV of the project as at the beginning of the scale-up stage is given by: \$45,982,497.6 - \$2,707,927 = \$43,274,570.7. The value of the project without managerial flexibility at this point is very high and positive implying that the project is viable. Compared with NPV3 the value of the project at the beginning of the scale-up stage has increased by about 39%. The value of the project at the beginning of the scale-up stage has increased because most of the technological risk surrounding the project has been resolved.

Calculation of ROV4

The real option payoff values and its associated investment strategies determined are presented in Table 5.16. From this table the real option value (ROV4) at the beginning of the scale-up stage obtained by valuing the project as a series of compound call options is \$43,990,438. This real option value is greater than the investment cost required to proceed with the first year scale-up stage research (i.e. \$500,000). Therefore the optimal decision would be to invest the initial \$500,000 and start with the first year scale-up research. This implies that the value of managerial flexibility associated with the canola research project at the beginning of the scale-up stage is \$43,490,438 (i.e. \$43,990,438 - \$500,000). In comparison with the NPV4, the real option analysis increases the estimate of the value of the project by 2%.

`5.3 Summary of Results

The analysis has shown that incorporating managerial flexibility into the analysis has a great impact on the estimate of the value of the canola meal enhancing R&D project. The overall value of the project using the traditional NPV model ignores the value of managerial flexibility. As a result the value of the project estimated is negative which indicates that the project should be abandoned. However when flexibility is included in the valuation, the overall estimate of the value of the project became positive and greater than the investment cost required to proceed with the next stage of R&D. The estimated real option value of the canola research project at the beginning of the various stages indicates that the management of the project should make the next R&D investment and proceed to the next R&D decision point.

When the project has successfully passed the basic R&D stage (i.e. when the risk surrounding basic research has completely been resolved), both NPV and real option models yields a positive estimate of the value of the project which is greater than the investment cost required to proceed with the next stage of R&D. This is because once the project passes the basic R&D stage, it becomes less risky. A key recommendation at this point would be that the real option approach should be restricted to high risk investment projects since managerial flexibility has a great value for such projects.

The real option values of the canola research project estimated at the start of basic R&D, applied R&D, prototype and scale-up stages are greater than the investment costs required to proceed to the next R&D stages respectively. This implies that once basic R&D is started, the technology could be taken all the way to the commercialization stage. The overall positive real option value of the project is likely to attract private biotechnology firms to take part in commercializing the canola meal enhancing technology. PBI's strategy to identify a collaborating firm to move the technology from the basic R&D stage down the innovation chain is supported by the results.

5.4 Tables for Chapter 5

Table 5.1 Base case Input Variables of the Quadranomial Model

Up move parameter			**1.09**	
Down move parameter			**0.91**	
Risk neutral probability of price moving up			**0.68**	
			Price Risk	
			Prob. up = ***0.68***	Prob. Down = ***0.32***
R&D Stage / Number of years	**Cumulative Tech. Risks**	**Annual Risks**		
Scale-up – 2 years	Prob. success = 0.85	***0.92***	0.62	0.30
	Prob. failure = 0.15	***0.08***	0.05	0.03
Prototype – 2 years	Prob. success = 0.75	***0.87***	0.58	0.28
	Prob. failure = 0.25	***0.13***	0.09	0.04
Applied R&D – 4 years	Prob. success = 0.60	***0.88***	0.59	0.29
	Prob. failure = 0.40	***0.12***	0.08	0.04
Basic R&D – 4 years	Prob. success = 0.30	***0.74***	0.50	0.24
	Prob. failure = 0.70	***0.26***	0.18	0.08

N.B: Annual technological risks × Price risk = Quadranomial risk-neutral probabilities in boxes

Tech = Technological. ***Prob*** = Probability of

Table 5.2 Evolution of Price Risk through Time for Canola Meal ($/tonne)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
years	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
	$208	$228	$249	$272	$298	$326	$357	$391	$427	$468	$512	$560	$612	$670
		$190	$208	$228	$249	$272	$298	$326	$357	$391	$427	$468	$512	$560
			$174	$190	$208	$228	$249	$272	$298	$326	$357	$391	$427	$468
				$159	$174	$190	$208	$228	$249	$272	$298	$326	$357	$391
					$145	$159	$174	$190	$208	$228	$249	$272	$298	$326
						$133	$145	$159	$174	$190	$208	$228	$249	$272
							$121	$133	$145	$159	$174	$190	$208	$228
								$111	$121	$133	$145	$159	$174	$190
									$101	$111	$121	$133	$145	$159
										$93	$101	$111	$121	$133
											$85	$93	$101	$111
												$77	$85	$93
													$71	$77
														$65

Table 5.3 **Scenario 1 (Basic R&D) - Overall Project's Value Tree without Flexibility**

	Basic R&D			Applied R&D			Prototype		Scale-up		Commercialization
1995	1996	~	1999	2000	~	2003	2004	2005	2006	2007	2008
0	**1**	~	**4**	**5**	~	**8**	**9**	**10**	**11**	**12**	**13**
$6,244,906	$9,227,247	~	$29,765,339	$36,982,781	~	$70,935,847	$89,569,815	$113,098,694	$134,145,057	$159,107,905	$173,987,602
	$7,707,244	~	$24,862,101	$30,890,615	~	$59,250,600	$74,814,998	$94,467,970	$112,047,370	$132,898,093	$145,326,662
		~	$20,766,572	$25,802,010	~	$49,490,261	$62,490,739	$78,906,281	$93,589,830	$111,005,819	$121,387,031
		~	$17,345,699	$21,551,651	~	$41,337,741	$52,196,653	$65,908,066	$78,172,797	$92,719,854	$101,390,971
			$14,488,346	$18,001,452	~	$34,528,184	$43,598,309	$55,051,045	$65,295,409	$77,446,132	$84,688,858
				$15,036,076	~	$28,840,363	$36,416,369	$45,982,498	$54,539,310	$64,688,447	$70,738,080
					~	$24,089,496	$30,417,508	$38,407,810	$45,555,061	$54,032,333	$59,085,411
						$20,121,239	$25,406,839	$32,080,900	$38,050,786	$45,131,598	$49,352,284
						$16,806,671	$21,221,575	$26,796,220	$31,782,688	$37,697,079	$41,222,493
							$17,725,750	$22,382,084	$26,547,132	$31,487,247	$34,431,920
								$18,695,088	$22,174,029	$26,300,360	$28,759,957
									$18,521,306	$21,967,907	$24,022,336
										$18,349,138	$20,065,141
											$16,759,815
	$0	~	$0	$0	~	$0	$0	$0	$0	$0	$0
	$0	~	$0	$0	~	$0	$0	$0	$0	$0	$0
		~	$0	$0	~	$0	$0	$0	$0	$0	$0
		~	$0	$0	~	$0	$0	$0	$0	$0	$0
			$0	$0	~	$0	$0	$0	$0	$0	$0
				$0	~	$0	$0	$0	$0	$0	$0
					~	$0	$0	$0	$0	$0	$0
					~	$0	$0	$0	$0	$0	$0
						$0	$0	$0	$0	$0	$0
							$0	$0	$0	$0	$0
								$0	$0	$0	$0
									$0	$0	$0
										$0	$0
											$0

Note: ~ implies that the table continues

Table 5.4 **Scenario 1 (Basic R&D) - Overall Present Value of Investment Cost without Flexibility**

		Basic R&D			**Applied R&D**			**Prototype**		**Scale-up**		**Commercialization**
	1995	1996	~	1999	2000		2003	2004	2005	2006	2007	2008
years	**0**	**1**	~	**4**	**5**		**8**	**9**	**10**	**11**	**12**	**13**
Basic R&D cost		$743,010	~	$743,010								
Applied R&D cost					$500,000	~	$500,000					
Prototype cost								$500,000	$500,000			
Scale up cost										$500,000	$500,000	
Commercialization cost												$1,949,215
Total investment cost		$743,010	~	$743,010	$500,000	~	$500,000	$500,000	$500,000	$500,000	$500,000	$1,949,215
PV of total investment cost		$717,884	~	$647,490	$420,987	~	$379,706	$366,865	$354,459	$342,473	$330,892	$1,246,336
PV of total investment cost		**$6,970,598**										

N.B: The investment cost are discounted at the risk-free rate (i.e. 3.5%)

Note: ~ implies that the table continues

Table 5.5 **Scenario 1 (Basic R&D) - Payoff Values of R&D Project with Flexibility**

	Basic R&D			Applied R&D			Prototype		Scale-up		Commercialization
1995	1996	~	1999	2000		2003	2004	2005	2006	2007	2008
0	**1**	~	**4**	**5**		**8**	**9**	**10**	**11**	**12**	**13**
$5,407,598	$8,148,956	~	$32,190,306	$40,793,960	~	$78,504,147	$96,540,565	$118,536,339	$136,543,047	$157,158,691	$173,987,602
	$6,343,670	~	$26,366,797	$33,558,378	~	$65,095,057	$80,181,636	$98,578,642	$113,671,941	$130,948,879	$145,326,662
		~	$21,502,594	$27,514,712	~	$53,894,844	$66,517,510	$81,908,572	$94,568,388	$109,056,604	$121,387,031
		~	$17,439,670	$22,466,618	~	$44,539,639	$55,104,273	$67,984,559	$78,611,758	$90,770,639	$101,390,971
ROV1			$14,046,031	$18,250,095	~	$36,725,515	$45,571,135	$56,354,246	$65,283,661	$75,496,917	$84,688,858
				$14,728,160	~	$30,198,611	$37,608,390	$46,639,792	$54,151,099	$62,739,232	$70,738,080
					~	$24,746,881	$30,957,346	$38,525,597	$44,852,401	$52,083,118	$59,085,411
					~	$20,193,215	$25,401,927	$31,748,053	$37,085,476	$43,182,383	$49,352,284
						$16,389,672	$20,761,651	$26,086,971	$30,597,995	$35,747,865	$41,222,493
							$16,885,766	$21,358,439	$25,179,195	$29,538,033	$34,431,920
								$17,408,837	$20,653,033	$24,351,145	$28,759,957
									$16,872,464	$20,018,693	$24,022,336
										$16,399,924	$20,065,141
											$16,759,815
	$0	~	$0	$0	~	$0	$0	$0	$0	$0	$0
	$0	~	$0	$0	~	$0	$0	$0	$0	$0	$0
		~	$0	$0	~	$0	$0	$0	$0	$0	$0
		~	$0	$0	~	$0	$0	$0	$0	$0	$0
			$0	$0	~	$0	$0	$0	$0	$0	$0
				$0	~	$0	$0	$0	$0	$0	$0
					~	$0	$0	$0	$0	$0	$0
					~	$0	$0	$0	$0	$0	$0
						$0	$0	$0	$0	$0	$0
							$0	$0	$0	$0	$0
								$0	$0	$0	$0
									$0	$0	$0
										$0	$0
											$0

Note: ~ implies that the table continues

Table 5.6 **Scenario 1 (Basic R&D) - Investment Strategies Associated with Payoff Values**

	Basic R&D			Applied R&D			Prototype		Scale-up		Commercialization
1995	1996	~	1999	2000	~	2003	2004	2005	2006	2007	2008
0	**1**	~	**4**	**5**	~	**8**	**9**	**10**	**11**	**12**	**13**
Invest (BRD)	Invest (BRD)	~	Invest (ARD)	Invest (ARD)	~	invest (P)	Invest (P)	Invest (S)	Invest (S)	invest Mkt	Market
	Invest (BRD)	~	Invest (ARD)	Invest (ARD)	~	invest (P)	Invest (P)	Invest (S)	Invest (S)	invest Mkt	Market
		~	Invest (ARD)	Invest (ARD)	~	invest (P)	Invest (P)	Invest (S)	Invest (S)	invest Mkt	Market
		~	Invest (ARD)	Invest (ARD)	~	invest (P)	Invest (P)	Invest (S)	Invest (S)	invest Mkt	Market
			Invest (ARD)	Invest (ARD)	~	invest (P)	Invest (P)	Invest (S)	Invest (S)	invest Mkt	Market
				Invest (ARD)	~	invest (P)	Invest (P)	Invest (S)	Invest (S)	invest Mkt	Market
					~	invest (P)	Invest (P)	Invest (S)	Invest (S)	invest Mkt	Market
					~	invest (P)	Invest (P)	Invest (S)	Invest (S)	invest Mkt	Market
						invest (P)	Invest (P)	Invest (S)	Invest (S)	invest Mkt	Market
							Invest (P)	Invest (S)	Invest (S)	invest Mkt	Market
								Invest (S)	Invest (S)	invest Mkt	Market
									Invest (S)	invest Mkt	Market
										invest Mkt	Market
											Market
	Abandon	~	Abandon	Abandon	~	Abandon	Abandon	Abandon	Abandon	Abandon	Abandon
	Abandon	~	Abandon	Abandon	~	Abandon	Abandon	Abandon	Abandon	Abandon	Abandon
		~	Abandon	Abandon	~	Abandon	Abandon	Abandon	Abandon	Abandon	Abandon
		~	Abandon	Abandon	~	Abandon	Abandon	Abandon	Abandon	Abandon	Abandon
			Abandon	Abandon	~	Abandon	Abandon	Abandon	Abandon	Abandon	Abandon
				Abandon	~	Abandon	Abandon	Abandon	Abandon	Abandon	Abandon
					~	Abandon	Abandon	Abandon	Abandon	Abandon	Abandon
					~	Abandon	Abandon	Abandon	Abandon	Abandon	Abandon
						Abandon	Abandon	Abandon	Abandon	Abandon	Abandon
							Abandon	Abandon	Abandon	Abandon	Abandon
								Abandon	Abandon	Abandon	Abandon
									Abandon	Abandon	Abandon
										Abandon	Abandon
											Abandon

Note: ~ implies that the table continues

Table 5.3 Estimated Project Values Given by the Four Scenarios Evaluated

	Base Assumptions	Duration (years)	NPV	ROV
Scenario 1 (Basic R&D)	PBI takes technology from BRD to commercialization.	13	-$725,692.1	$5,407,597.8
Scenario 2 (Applied R&D)	BRD investment cost sunk	9	$15,899,395.2	$18,986,956.8
Scenario 3 (Prototype)	BRD and ARD investment costs sunk	5	$31,050,457.8	$32,365,041.0
Scenario 4 (Scale-up)	BRD, ARP and P investment costs sunk	3	$43,274,570.7	$43,990,438.3

BRD = Basic R&D stage. ***ARD*** = Applied R&D stage. ***P*** = Prototype stage.

Table 5.4 Scenario 2 - Project's Value Tree from the Applied R&D Stage

	Applied R&D			**Prototype**		**Scale-up**		**Commer-cialization**
1999	2000	~	2003	2004	~	2006	2007	2008
0	**1**	~	**4**	**5**	~	**7**	**8**	**9**
$20,766,572	$25,802,010	~	$49,490,261	$62,490,739	~	$93,589,830	$111,005,819	$121,387,031
	$21,551,651	~	$41,337,741	$52,196,653	~	$78,172,797	$92,719,854	$101,390,971
		~	$34,528,184	$43,598,309	~	$65,295,409	$77,446,132	$84,688,858
		~	$28,840,363	$36,416,369	~	$54,539,310	$64,688,447	$70,738,080
			$24,089,496	$30,417,508	~	$45,555,061	$54,032,333	$59,085,411
				$25,406,839	~	$38,050,786	$45,131,598	$49,352,284
					~	$31,782,688	$37,697,079	$41,222,493
					~	$26,547,132	$31,487,247	$34,431,920
							$26,300,360	$28,759,957
								$24,022,336
	$0	~	$0	$0	~	$0	$0	$0
	$0	~	$0	$0	~	$0	$0	$0
		~	$0	$0	~	$0	$0	$0
		~	$0	$0	~	$0	$0	$0
			$0	$0	~	$0	$0	$0
				$0	~	$0	$0	$0
					~	$0	$0	$0
						$0	$0	$0
							$0	$0
								$0

Note: ~ implies that the table continues

Table 5.5 Scenario 2 - Present Value of Investment Costs from the Applied R&D Stage

		Applied R&D			**Prototype**		**Scale-up**		**Commer cialization**
	1999	2000	~	2003	2004	~	2006	2007	2008
years	**0**	**1**	~	**4**	**5**		**7**	**8**	**9**
Applied R&D cost		$500,000	~	$500,000					
Prototype cost					$500,000	~			
Scale up cost							$500,000	$500,000	
Commercialization cost									$1,949,215
Total investment cost		$500,000	~	$500,000	$500,000		$500,000	$500,000	$1,949,215
PV of investment cost		$483,092	~	$435,721	$420,987		$392,995	$379,706	$1,430,199
PV of total investment cost		**$4,867,177**							

Note: ~ implies that the table continues

Table 5.6 Scenario 2 (Applied R&D) – Payoff Values / Investment Strategies

	Applied R&D			Prototype		Scale-up		Commer-cialization
1999	2000	~	2003	2004	~	2006	2007	2008
0	**1**	~	**4**	**5**	~	**7**	**8**	**9**
$18,986,957	$23,757,534	~	$48,521,377	$62,047,415	~	$94,568,388	$109,056,604	$121,387,031
	$19,358,411	~	$40,083,519	$51,393,036	~	$78,611,758	$90,770,639	$101,390,971
		~	$33,035,627	$42,493,750	~	$65,283,661	$75,496,917	$84,688,858
		~	$27,148,733	$35,060,442	~	$54,151,099	$62,739,232	$70,738,080
↓			$22,231,585	$28,851,621	~	$44,852,401	$52,083,118	$59,085,411
ROV2				$23,665,578	~	$37,085,476	$43,182,383	$49,352,284
					~	$30,597,995	$35,747,865	$41,222,493
						$25,179,195	$29,538,033	$34,431,920
							$24,351,145	$28,759,957
								$24,022,336
	$0	~	$0	$0	~	$0	$0	$0
	$0	~	$0	$0	~	$0	$0	$0
		~	$0	$0	~	$0	$0	$0
		~	$0	$0	~	$0	$0	$0
			$0	$0	~	$0	$0	$0
				$0	~	$0	$0	$0
					~	$0	$0	$0
						$0	$0	$0
							$0	$0
								$0
Investment strategies								
Invest (ARD)	Invest (ARD)	~	Invest (P)	Invest (P)	~	Invest (S)	Invest Mkt	Market
	Invest (ARD)	~	Invest (P)	Invest (P)	~	Invest (S)	Invest Mkt	Market
		~	Invest (P)	Invest (P)	~	Invest (S)	Invest Mkt	Market
		~	Invest (P)	Invest (P)	~	Invest (S)	Invest Mkt	Market
			Invest (P)	Invest (P)	~	Invest (S)	Invest Mkt	Market
				Invest (P)	~	Invest (S)	Invest Mkt	Market
					~	Invest (S)	Invest Mkt	Market
						Invest (S)	Invest Mkt	Market
							Invest Mkt	Market
								Market
	Abandon	~	Abandon	Abandon	~	Abandon	Abandon	Abandon
	Abandon	~	Abandon	Abandon	~	Abandon	Abandon	Abandon
		~	Abandon	Abandon	~	Abandon	Abandon	Abandon
		~	Abandon	Abandon	~	Abandon	Abandon	Abandon
			Abandon	Abandon	~	Abandon	Abandon	Abandon
				Abandon	~	Abandon	Abandon	Abandon
					~	Abandon	Abandon	Abandon
						Abandon	Abandon	Abandon
							Abandon	Abandon
								Abandon

Note: ~ implies that the table continues

Table 5.7 Scenario 3 - Project's Value Tree from the Prototype Stage

	Prototype		Scale-up		Commercialization
2003	2004	2005	2006	2007	2008
0	**1**	**2**	**3**	**4**	**5**
$34,528,183.8	$43,598,309.4	$55,051,044.5	$65,295,409.1	$77,446,131.7	$84,688,858.0
	$36,416,369.1	$45,982,497.6	$54,539,310.1	$64,688,446.8	$70,738,080.3
		$38,407,810.5	$45,555,061.1	$54,032,332.6	$59,085,411.3
			$38,050,785.5	$45,131,597.9	$49,352,284.0
				$37,697,079.3	$41,222,492.7
					$34,431,920.2
	$0.0	$0.0	$0.0	$0.0	$0.0
	$0.0	$0.0	$0.0	$0.0	$0.0
		$0.0	$0.0	$0.0	$0.0
			$0.0	$0.0	$0.0
				$0.0	$0.0
					$0.0

Table 5.8 Scenario 3 - Present Value of Investment Cost from the Prototype Stage

		Prototype		Scale-up		Commercialization
	2003	2004	2005	2006	2007	2008
years	**0**	**1**	**2**	**3**	**4**	**5**
Prototype cost		$500,000	$500,000			
Scale up cost				$500,000	$500,000	
Commercialization cost						$1,949,215
Total investment cost		$500,000	$500,000	$500,000	$500,000	$1,949,215
Discounted investment cost		$483,092	$466,755	$450,971	$435,721	$1,641,186
PV of total investment cost	**$3,477,726**					

Table 5.9 Scenario 3 (Prototype) – Real Option Payoff Values / Investment Strategies

		Prototype		Scale-up		Commercialization
	2003	2004	2005	2006	2007	2008
years	**0**	**1**	**2**	**3**	**4**	**5**
	$32,365,041.0	$41,013,104.9	$52,558,985.2	$63,059,093.1	$75,496,917.2	$84,688,858.0
		$33,831,164.6	$43,490,438.3	$52,302,994.2	$62,739,232.3	$70,738,080.3
			$35,915,751.2	$43,318,745.2	$52,083,118.1	$59,085,411.3
				$35,814,469.6	$43,182,383.4	$49,352,284.0
					$35,747,864.8	$41,222,492.7
	ROV3					$34,431,920.2
		$0.0	$0.0	$0.0	$0.0	$0.0
		$0.0	$0.0	$0.0	$0.0	$0.0
			$0.0	$0.0	$0.0	$0.0
				$0.0	$0.0	$0.0
					$0.0	$0.0
						$0.0
Investment strategies						
	Invest (P)	Invest (P)	Invest (S)	Invest (S)	Invest (Mkt)	Market
		Invest (P)	Invest (S)	Invest (S)	Invest (Mkt)	Market
			Invest (S)	Invest (S)	Invest (Mkt)	Market
				Invest (S)	Invest (Mkt)	Market
					Invest (Mkt)	Market
						Market
		Abandon	Abandon	Abandon	Abandon	Abandon
		Abandon	Abandon	Abandon	Abandon	Abandon
			Abandon	Abandon	Abandon	Abandon
				Abandon	Abandon	Abandon
					Abandon	Abandon
						Abandon

Table 5.10 Scenario 4 - Project's Value Tree from the Scale-up Stage

		Scale-up		Commercialization
	1995	1996	1997	1998
years	**0**	**1**	**2**	**3**
	$45,982,497.6	$54,539,310.1	$64,688,446.8	$70,738,080.3
		$45,555,061.1	$54,032,332.6	$59,085,411.3
			$45,131,597.9	$49,352,284.0
				$41,222,492.7
		$0.0	$0.0	$0.0
		$0.0	$0.0	$0.0
			$0.0	$0.0
				$0.0

Table 5.11 Scenario 4 - Present Value of Investment Costs from the Scale-up Stage

		Scale-up		Commercialization
	1995	1996	1997	1998
years	**0**	**1**	**2**	**3**
Scale up cost		$500,000	$500,000	
Commercialization cost				$1,949,215
Total investment cost		$500,000	$500,000	$1,949,215
Discounted investment cost		$483,092	$466,755	$1,758,080
PV of investment costs	**$2,707,927**			

Table 5.12 Scenario 4 (Scale-up) - Real Option Payoff Values / Investment Strategies

		Scale-up		Commercialization
years	**0**	**1**	**2**	**3**
	$43,990,438.3	$52,302,994.2	$62,739,232.3	$70,738,080.3
		$43,318,745.2	$52,083,118.1	$59,085,411.3
			$43,182,383.4	$49,352,284.0
				$41,222,492.7
	ROV4	$0.0	$0.0	$0.0
		$0.0	$0.0	$0.0
			$0.0	$0.0
				$0.0
Investment strategies				
	Invest (S)	Invest (S)	Invest (Mkt)	Market
		Invest (S)	Invest (Mkt)	Market
			Invest (Mkt)	Market
				Market
		Abandon	Abandon	Abandon
		Abandon	Abandon	Abandon
			Abandon	Abandon
				Abandon

CHAPTER 6 SENSITIVITY ANALYSIS OF THE CANOLA R&D PROJECT

The models estimated in chapter 5 have an underlying assumption that the reduced ANF canola meal once fully commercialized is completely substitutable for soybean meal. Thus the value of the project estimated is based on the full price difference between reduced ANF canola meal and that of the unreduced or conventional canola meal. Investors were assumed to fully capture all the dollar value of meal benefit (i.e. 23% of the price of reduced ANF canola meal or $48) when the technology is fully commercialized. This assumption was imposed because the research is publicly funded. If all of the benefits from commercializing the reduced ANF canola meal are captured by investors, then, there is no incentive for a private biotechnology firm who is interested in commercializing the technology to adopt it. Thus, from the standpoint of private firms, the assumption that investors capture all the benefit if the technology is fully commercialized may not be feasible.

Also, a yearly exercise pattern and time step is assumed to calculate the real option value of the project. The expenditures for each stage in the R&D timeline were aggregated and assumed to be invested equally. This in research terms implies that the uncertainties associated with the investment cost of the project are resolved at the end of each year of the R&D process. PBI is able to learn enough about the research process by the end of each year to be able to make the decision to either continue to invest or abandon the research project. Also, it indicates that PBI adopts a yearly review of the canola R&D project. A yearly review of the canola project, however, is not consistent with PBI's review process. PBI uses a three-year review process and evaluation of its research programme is done using provisions stated in the organization's five-year strategic plan.

The model assumptions and some of the input variables used in the analysis in chapter 5 raise certain key questions. These questions are categorized as those relating to model assumptions and those relating to the input variables of the model. The questions are as follows.

1. How sensitive is the valuation results to changes in the assumptions of the model?
   - What if the reduced ANF canola meal is not completely substitutable for soybean meal? If the reduced ANF canola meal is not completely

substitutable for soybean meal, then, how much of the benefit of the reduced ANF canola meal could be captured by investors given the sales volume of 225,000 metric tonnes?

- Also, what if the uncertainties about the research costs are not resolved at the end of every year but rather at the end of a particular stage in the R&D timeline? That is, what if PBI or any potential firm commercializing the technology, is only able to fully learn about the difficulty of the research project as it continues to invest until the end of a particular stage in the R&D timeline?
- Also, given the same exercise pattern, how sensitive is the valuation results to more time steps in this specialized version of the binomial model?

2. How sensitive is the valuation results to changes in the input variables of the model?
    - That is, holding all other parameters constant, how sensitive is the valuation results to changes in the probability of success associated with the R&D stages independently as well as the case where all the probabilities of success changes together by the same magnitude?
    - Holding all other parameters constant, how sensitive is the valuation results to changes in price volatility?
    - Holding all other parameters constant, how sensitive is the valuation results to changes in the risk-free rate?
    - Holding all other parameters constant, how sensitive is the valuation results to changes in the discount rate?
    - Holding all other parameters constant, how sensitive is the valuation results to changes in the quantity of reduced ANF canola meal sold per year? What would be the break-even quantity of reduced ANF canola meal sold per year and how many hectares of canola in Western Canada is required to produce this sales volume?
    - Holding all the other input variables of the model constant, how sensitive is the valuation results to a variation of the price of reduced ANF canola

meal from the upper bound value ($208) to the lower bound value (i.e. price of unreduced or conventional canola meal, $160)? In other words how sensitive is the valuation results to a variation of the price of reduced ANF canola meal captured by investors from the base case 23% of $208 to 0% of $208?

- Given a sales volume of 225,000 metric tonnes (i.e. sales volume for a private firm) what would be the break-even reduced ANF canola meal price? From the standpoint of a private biotechnology firm, who is interested in commercializing the technology, it is important to know what the break-even reduced ANF canola meal price given by this project would be. That is, how much of the reduced ANF canola meal price, a private firm must capture, to make the project still attractive.
- In addition, given a sales volume of 3,990,310 metric tones (i.e. total sales volume for the entire canola industry) what would be the break-even reduced ANF canola meal price? Since the canola technology is a platform one, and thus could be incorporated into nearly all canola varieties in Western Canada, it is important to know what the break-even canola meal price for the entire canola industry would be as well as the implication of that on public policy.
- Finally, holding all other parameters constant, how sensitive is the valuation results to changes in the R&D costs of the project? The analysis in chapter 5 assumed that the R&D investment costs at each stage are known. What if the costs are not known? What would be the break-even R&D investment cost for each stage of the R&D timeline?

In this chapter, a sensitivity analysis is conducted to determine how these questions impacts on the valuation results. Scenarios 1 and 2 (i.e. basic and applied R&D scenarios respectively) are chosen for the analysis. Scenario 1 is chosen because of the need to determine if a particular analysis performed could significantly alter the overall investment policy of the project. Scenario 2 is chosen because as explained in PBI's business model, the beginning of the applied R&D stage is where private firms are attracted to help commercialize the technology. When the technology successfully passes the basic R&D stage, it becomes less risky, thus the estimated value of the project is greater than the investment cost required to proceed with the next stage of R&D. In view of this, it is expected that the investment strategies that would result from any sensitivity analysis performed on Scenario 2 would not be different from the sensitivity results given by Scenario 3 and 4 (start of prototype or scale-up stages respectively).

6.1 Sensitivity of NPV and ROV to Changes in the Assumptions of the Models

This analysis examines how the valuation results respond to changes in the underlying assumptions of the initial models estimated in chapter 5. Specifically the analysis investigates how the NPV and real option results respond to:

- Changes in the benefit received by investors.
- Changes in different exercise patterns.
- More time steps and the same exercise times.

6.1.1 Sensitivity of NPV and ROV to Changes in the Benefit Received by Investors

To model the question of substitutability of the reduced ANF canola meal for soybean meal, the increased dollar value of meal benefit captured per metric tonne of reduced ANF canola meal sold, is varied in the analysis. Three versions of the initial NPV and ROV models estimated in chapter 5 are evaluated to determine how much of the increased dollar value of meal benefit potential private investors must capture to make the project feasible. These versions of the model assume that for each metric tonne of reduced ANF canola meal sold, investors capture 75%, 50% or 25% respectively of the potential benefit of 23% of $208. All other input variables of the model as shown by Tables 4.2 and 5.1 as well as the sales volume and discount rate in Table 4.6 are held constant. The scenarios of these versions are denoted with the alphabets *b, c*, and *d* respectively. These are reported in Table C.1 (Appendix C). The results from these versions of scenarios 1 and 2 are compared with those of the initial models. For the sake of comparison, the results from the scenarios of the initial NPV and ROV models evaluated in chapter 5 are denoted with the alphabet *a*.

The estimated NPV and ROV given by the various scenarios that are compared in this sensitivity analysis are described as follows.

- NPV1*a* = NPV of the canola research project given by scenario 1*a* (basic R&D). The assumption is that investors capture 0.23 × $208. This is the base case value.
- NPV1*b* = NPV of the canola research project given by scenario 1*b* (basic R&D). The assumption is that investors capture 0.75 × 0.23 × $208 (i.e. 0.17 × $208).
- NPV1*c* = NPV of the canola research project given by scenario 1*c* (basic R&D). The assumption is that investors capture 0.50 × 0.23 × $208 (i.e. 0.12 × $208).
- NPV1*d* = NPV of the canola research project given by scenario 1*d* (basic R&D). The assumption is that investors capture 0.25 × 0.23 × $208 (i.e. 0.06 × $208).

- ROV1*a* = Real option value of the canola research project given by scenario 1*a* (basic R&D). The assumption is that investors capture 0.23 × $208. This is the base case value.
- ROV1*b* = Real option value of the canola research project given by scenario 1*b* (basic R&D). The assumption is that investors capture 0.75 × 0.23 × $208 (i.e. 0.17 × $208).
- ROV1*c* = Real option value of the canola research project given by scenario 1*c* (basic R&D). The assumption is that investors capture 0.50 × 0.23 × $208 (i.e. 0.12 × $208).
- ROV1*d* = Real option value of the canola research project given by scenario 1*d* (basic R&D). The assumption is that investors capture 0.25 × 0.23 × $208 (i.e. 0.06 × $208).

- NPV2*a* = NPV of the canola research project given by scenario 2*a* (applied R&D).
  The assumption is that investors capture 0.23 × $208. This is the base case value.
- NPV2*b* = NPV of the canola research project given by scenario 2*b* (applied R&D).
  The assumption is that investors capture 0.75 × 0.23 × $208 (i.e. 0.17 × $208).
- NPV2*c* = NPV of the canola research project given by scenario 2*c* (applied R&D).
  The assumption is that investors capture 0.50 × 0.23 × $208 (i.e. 0.12 × $208).

- NPV2*d* = NPV of the canola research project given by scenario 2*d* (applied R&D).

  The assumption is that investors capture 0.25 × 0.23 × $208 (i.e. 0.06 × $208).

- ROV2*a* = Real option value of the canola research project given by scenario 2*a* (applied R&D). The assumption is that investors capture 0.23 × $208. This is the base case value.
- ROV2*b* = Real option value of the canola research project given by scenario 2*b* (applied R&D). The assumption is that investors capture 0.75 × 0.23 × $208 (i.e. 0.17 × $208).
- ROV2*c* = Real option value of the canola research project given by scenario 2*c* (applied R&D). The assumption is that investors capture 0.50 × 0.23 × $208 (i.e. 0.12 × $208).
- ROV2*d* = Real option value of the canola research project given by scenario 2*d* (applied R&D). The assumption is that investors capture 0.25 × 0.23 × $208 (i.e. 0.06 × $208).

The basic assumption of scenarios *b, c* and *d* imply that investors capture 17% of the price of improved meal (or $36), 12% of the price of improved meal (or $24) and 6% of the price of improved meal (or $12) respectively as benefit from each tonne of reduced ANF canola meal sold at a base price of $208. This implies that once the reduced ANF canola meal is commercialized, 83%, 88% and 94% respectively of the revenue will constitute the other cost for example production, processing and marketing costs etc. associated with producing the improved meal (equation 4.1). It is worth noting that once the reduced ANF canola seed is commercialized it would lead to the creation of a supply chain involving identity preservation of the reduced ANF canola seed/meal and that of the unreduced ANF seed/meal. Identity preserved supply chains may have higher marketing cost. As pointed out in section 4.5.3, the cost for identity preservation may vary depending on whether it is segregation which traces back to a particular producer or field or that which trace back to a particular grain elevator company.

The results of scenarios *b*, *c* and *d* are presented in Figure 6.1 (also see Appendix C.1 for the table of results). From the results, NPV1 is negative for all the three scenario versions evaluated. The investment decision given by the NPV approach would be to abandon the project. The ROV of the project from scenarios *b* and *c*, are greater than the investment cost required to proceed to the next R&D stages respectively. The investment decision given by those ROV values would be to invest in the next stage of the project. The ROV of the entire project from scenario 1*d* is zero. Thus the investment decision would be to abandon the entire project when investors capture 6% of the price of improved meal (i.e. $12) as benefit per metric tonne of meal sold. The ROV of the project from the start of applied research (i.e. scenario 2*d*) however is greater than $500,000 which is the initial investment cost required to start the first year applied R&D. As the benefit captured by investors per metric tonne of meal sold decreased, both the NPV and ROV decreased.

Using Goal Seek in Excel and an improved canola meal sales volume of 225,000, the real option value of the research project at the basic R&D stage was found to be greater than $743,010 when the benefit captured by investors is above 8.5% of the price of improved meal or $18. With this benefit, the other cost associated with producing the improved meal is estimated to be 91.5% of revenue. When the benefit captured is below 8.5% of the price of improved meal, the project is not feasible with RO analysis.

6.1.2 Sensitivity of ROV to Different Exercise Patterns

To model the question of the resolution of the uncertainties surrounding the research cost, the yearly exercise pattern used in estimating the real option value in the initial model is changed and exercise of the call option on the next stage is permitted only at the beginning of a particular stage in the product development process. This implies that PBI is only able to resolve the uncertainties surrounding the research costs when they have gone through the entire stage. Thus, PBI makes the decision to either continue to invest or abandon the project with the information acquired from the completion of the previous stage's investment. Also, it implies that PBI reviews the project only at the end of each phase of the product development process. The scenarios evaluated in this analysis are denoted with the alphabet *e*.

The overall R&D timeline of the project using the new exercise pattern consists of a series of five (5) call options in a sequence (scenario 1*e*). The R&D timeline of the project from the applied R&D stage consists of a series of four (4) call options (scenario 2*e*). In this analysis the real option value of the project, estimated at time period t=0, refers to the value of managerial flexibility. It does not include the investment cost required to proceed to the next stage of the innovation chain. As a result it is compared to the estimated value of managerial flexibility given by the models evaluated in chapter 5.

The description of the overall R&D timeline of this model (i.e. scenario 1*e*) using Figure 4.2 is as follows. The decision points are t=0, t=4, t=8, t=10 and t=12. The first call option (i.e. invest in basic R&D) expires in 4 years and it has an exercise price equal to the present value of the total cost invested in the basic R&D stage. If the basic R&D call option is exercised, PBI receives a second call option with a maturity time of 4 years. This second call option which gives PBI the right but not the obligation to invest in applied R&D has an exercise price equal to the present value of the total applied R&D stage cost. If the second call option is exercised, PBI receives a third call option with a maturity time of 2 years. This third call option gives PBI the right but not the obligation to invest in the prototype stage and this has an exercise price equal to present value of the total prototype stage investment cost. If the third call option is exercised, PBI will receive a fourth call option with a maturity time of 2 years. This fourth call option gives PBI the right but not the obligation to invest in the scale-up stage and this has an exercise price equal to the present value of the total scale-up stage investment cost. If the fourth call option is exercised, PBI will receive a fifth call option which gives PBI the right but not the obligation to commercialize the reduced ANF canola seed. This has an exercise price equal to the present value of the total commercialization investment cost.

The results are presented in Figure 6.2 (Table C.2). The calculated ROV of the project is sensitive to the exercise pattern adopted. By comparing ROV1*a* with ROV1*e*, the value of the project decreased from $4.66 million (i.e. 5.41 million – 0.74 million) to $2.8 million. The percent change associated with this decrease is approximately 40%. Similarly, by comparing ROV2*a* with ROV2*e*, the value of the project decreased from $18.49 million (i.e. $18.99 million – 0.50 million) to $17.31 million. The percentage decrease is however only 6%. The results show that when PBI commits to the entire cost of an R&D stage the estimated value of managerial flexibility is decreased. The above results suggest that the value of the project is very sensitive to the exercise patterns associated with the basic R&D stage and less sensitive to the applied R&D stage. The implication of this result is that a policy to pre-commit to the entire cost during the basic R&D stage is likely to cause a significant reduction to the value of managerial flexibility associated with the project as compared to one that considers yearly costs.

6.1.3 Sensitivity of NPV and ROV to More Time Steps given the same Exercise Times

This analysis is done by changing the time steps in both NPV and RO models from annual to every half year (i.e. every six months). This changes the risk neutral probability of an up move in price from 68% to 76%. The technological probabilities of success or risks for each stage in the model are therefore converted to half year risks (section 5.1.3). Due to the assumption of independence equation (3.10) is used to determine the half year quadranomial risk neutral probabilities specific to each stage of the R&D timeline. These half year probabilities are then used to estimate the value of the project.

The results of this sensitivity analysis are presented in Figure 6.3 (Table C.3). NPV1 increased in absolute terms from -$0.73 million to -$0.75 million while NPV2 increased from $15.90 million to $15.94 million. The explanation for the increase in the NPV is because of the increase in the probabilities used to estimate the value of the research project. ROV1 also increased from $5.41 million to $8.78 million while ROV2 increased from $18.99 million to $26 million. The percentage increase associated with ROV1 and ROV2 are 62% and 37% respectively. Hull, (2002) pointed out that increase in time steps improves the accuracy of the binomial option model thereby yields higher estimated values of the option. The results suggest that the real option value of the project is sensitive to the number of time steps in the model.

6.2 Sensitivity of NPV and ROV to Changes in the Initial Model's Input Variables

This analysis examines how the NPV and ROV results respond to changes in some of the input variables of the initial models estimated in chapter 5. Specifically the analysis investigates how NPV and ROV of the project respond to:

- Changes in the probability of success associated with the R&D stages (i.e. basic R&D risk, applied R&D risk, prototype risk and scale-up risk).
- The case when all technological risks shift down by the same magnitude.
- Movements in price volatility.
- Changes in the risk-free rate.
- Changes in the discount rate.
- Changes in the yearly sales volume (quantity of reduced ANF canola meal sold per year).
- Variation in the price of reduced ANF canola meal from the upper bound value of $208 to the lower bound value of $160 given a sales volume of 225,000 or 3,990,310 tonnes respectively.
- Changes in the R&D investment costs (exercise prices) of the project.

From the models estimated in chapter 5, the estimated real option values of the research project for scenarios 1 and 2 are greater than the initial investment cost required to proceed with the first year basic and applied R&D respectively, however only the NPV of scenario 2 (applied R&D) is positive, thus the values of the input variables above which the NPV of the project at the basic R&D stage (scenario 1) is positive are determined during the sensitivity analysis. These are reported in Table 6.1.

6.2.1 Sensitivity of NPV and ROV to Changes in the Probability of Success for Basic R&D

This analysis is limited to scenario 1 (Basic R&D) and is done by varying the probability of success associated with basic R&D from 5% to 75%. The results of this sensitivity analysis are presented in Figure 6.4 (Table C.4). The NPV and ROV curves have positive slopes and they are uniform. With a base case basic R&D probability of 30%, NPV and ROV are approximately -$0.73 million and $5.41 million respectively.

In general, the analysis shows that there is a positive relationship between the basic R&D probability of success and the value of the project with or without managerial flexibility. The results indicate that the RO model is more sensitive to the basic R&D probability of success than the NPV model. From the analysis the project is not feasible by the NPV criterion when the probability of success for the basic R&D stage is below 33%. When the probability of success associated with basic research is above this level of risk, the NPV of the research project is positive. This is shown by the positive NPV values in Table C.3. Since 33% probability of success for basic R&D is not too different from the base case basic R&D probability of 30%, the NPV approach should not be totally excluded when valuing biotech innovations from the basic R&D stage.

6.2.2 Sensitivity of NPV and ROV to Changes in Applied R&D Probability of Success

Even though a range of 50% to 60% is identified by the management of the project as the probability of success associated with applied research, the analysis is done by varying the probability of success from 25% to 85%. The results of this sensitivity analysis are presented in Figure 6.5 (Table C.5). As the probability of success for the applied R&D stage is increased, the estimated value of the project also increased. With a base case applied R&D probability of success of 60%, NPV1 and ROV1 are approximately -$0.73 million and $5.41 million respectively while NPV2 and ROV2 are $15.90 million and $18.99 million respectively.

At the lower bound probability of success value of 50%, NPV1 decreased by approximately 143% from -$0.73 million to -$1.77 million. NPV2 on the other hand decreased by 22% from $15.90 million to $12.44 million. Hence the investment decision would be to abandon the project at the basic R&D and invest at the applied R&D. At the same level of probability of success, ROV1 decreased by 21% from $5.41 million to $4.26 million while ROV2 decreased by 17% from $18.99 million to $15.73 million. NPV1 is zero when the probability of success for the applied R&D stage is approximately 67%.

6.2.3 Sensitivity of NPV and ROV to Changes in Prototype Stage Probability of Success

A range of 70% to 75% is identified as the probability of success associated with prototype research. The sensitivity analysis is done by varying the probability of success from 35% to 95%. The results are presented in Figure 6.6 (Table C.6). At the lower bound probability of success value of 70%, NPV1 and ROV1 are -$1.14 million and $4.93 million respectively while NPV2 and ROV2 are $14.51 million and $17.62 million respectively. NPV1 is zero when the probability of success for the prototype stage is approximately 84%.

6.2.4 Sensitivity of NPV and ROV to Changes in Scale-up Stage Probability of Success

This sensitivity analysis is done by varying the scale-up probability of success from 40% to 100%. The results of this sensitivity analysis are presented in Figure 6.7 (Table C.7). At the lower bound probability of success value of 80% NPV1 and ROV1 are -$1.09 million and $4.98 million respectively while NPV2 and ROV2 are $14.68 million and $17.76 million respectively. NPV1 is zero when the probability of success for the scale-up stage is approximately 95%.

6.2.5 Sensitivity of NPV and ROV to a Decrease in All Technological Probabilities

This sensitivity analysis is done by decreasing the technological probabilities of success for each stage from their base case values using increments of 2%. The range used is thus from the base case value of a particular probability of success to a 22% decrease. The results of this sensitivity analysis are presented in Figure 6.8 (Table C.8). As the probabilities are decreased from their base case values, the estimated value of the project also decreases. The overall research project is negative with NPV analysis. When all the probabilities are decreased by up to 14%, the overall real option value of the project is $0.82 million. This value is greater than $743,010. This implies that, when the probability of success associated with the basic R&D, applied R&D, prototype and scale-up stages are as low as 16%, 46%, 61% and 71% respectively, the real option value of the canola project is greater than the initial investment cost required to start the first year basic R&D. Therefore, at or above these probabilities of success, the investment decision would be to invest the initial $743,010 and start the first year basic R&D. The real option value of the project is less than the initial investment cost required to start the first year basic R&D when the probabilities of success are below these values.

6.2.6 Sensitivity of NPV and ROV to Changes in Price Volatility

The reduced ANF canola meal price volatility estimate in this analysis is not the volatility estimate of the underlying value of the project. It is therefore not directly linked to the discount rate of the project. The analysis is done by varying price volatility from 1% to 150%. A change in price volatility leads to a change in the probability of the price moving up or down. The results are presented in Figure 6.9 (Table C.9).

Overall the results show that while price volatility has no relationship with both NPV1 and NPV2, it is positively related to the ROV1 and ROV2. ROV1 initially is not sensitive to price volatility over the range of 1 to 30%. Thereafter a positive relationship is observed. Similarly ROV2 is not affected by price volatility over the range of 1% to 50. A change from 9% to 150% produced approximately 17% and 6% change in ROV1 and ROV2 respectively. This suggests that ROV1 is more sensitive to price volatility as compared to ROV2.

The fact that both NPV1 and NPV2 are not sensitive to price volatility is quite interesting. The intuitive explanation to this is as follows. First it is worth noting that any change in the NPV would have to come about via a change in the gross present value of the project. An increase in price volatility in this model has two fold results. The first is that the up move parameter increases and the down move parameter decreases. This results in higher prices through time however the risk neutral probability of the price moving up decreases. A decrease in the risk neutral probability leads to smaller quadranomial risk neutral probabilities used to determine the certainty equivalent cash flows given successful commercialization. In effect both impacts cancel out hence the gross present values determined did not change.

6.2.7 Sensitivity of NPV and ROV to Changes in the Risk-Free Rate

The result of the effect of changes in the risk-free rate on the value of the project is presented in Figure 6.10 (Table C.10). Overall, the results show that higher risk-free rates boost the value of the project with and without managerial flexibility. Thus investors who acquire the project by way of a call option obtain higher return on their investment as a result of paying the purchase price of the option (i.e. investment costs). This accounts for the upward sloping NPV and ROV curves in Figure 6.10. The intuitive explanation for the increase in the project's value is as follows. Most of the cash flows consist of investment costs. These costs are discounted at a higher rate thus the present value of investment expenditures become lower as compared with the present value of the project future cash flows.

6.2.8 Sensitivity of NPV and ROV to Changes in the Discount Rate

The discount rate is used in this analysis to capture the commercialization value of the project. It is not directly linked to the two key risks (i.e. technological and price) affecting the value of this R&D project. The analysis examined how variation in this parameter impacts on the investment decision given by the NPV and ROV models. The discount rate is varied from 5% to 50%. The results are presented in Figure 6.11 (Table C.11).

The results show that a negative relationship exists between the discount rate and the value of the project. As the discount rate is decreased from the base case value of 20% the value of the project increased. Alternatively, as the discount rate is increased the project's value decreased. The NPV and ROV values are more sensitive to a reduction in the discount rate than to an increase. When the discount rate is decreased to 5% the value of the project increased significantly. Using the NPV criterion, the results show that PBI can take the technology from basic research through to commercialization when the value of the project once commercialize is approximately six times the estimated free cash flows (i.e. 18% discount rate).

6.2.9 Sensitivity of NPV and ROV to Changes in the reduced ANF Sales Volume

This sensitivity analysis is done by varying the sales volume from 225,000 metric tonnes (i.e. 6% market share) to the estimated total volume of 3,990,310 metric tonnes[11]. The total volume of canola meal produced is used because the reduced ANF canola seed can potentially replace all canola seeds grown in Western Canada given successful commercialization. Since the canola meal enhancing technology is a platform technology, the genes responsible for reduced ANF may be incorporated into the conventional canola varieties to yield meals with reduced ANF. As discussed in section 4.5.2, the reduced

[11] This value is reported in Table 4.5. It is the average canola meal produced from 1995 to 2001 in Canada.

ANF canola meal sales volume of 225,000 tonnes, translates to about 375,000 tonnes of canola seed or canola crop area of 249,335 hectares. On the other hand the total sales volume of 3,990,310 metric tones of canola meal translates into 6,650,517 tonnes of canola seed or canola crop area of 4,421,886 hectares.

The results are presented in Figure 6.12 (Table C.12). Overall, a positive relationship is observed between the sales volume and the value of the research project. This implies that the project's value increases as the sales volume is increased. The results show that with a yearly sales volume of 251,146 metric tonnes (i.e. 6.3% market share) NPV1 is zero. This sales volume translates into 418,577 tonnes of canola seed or canola crop area of 278,309 hectares. Above this sales volume of 251,146 metric tones, the estimated value of the project is positive using the NPV analysis. In comparison to the historical yearly volume of canola meal utilized domestically in Canada (Table 4.5) this sales volume is realistic.

6.2.10 Sensitivity of NPV and ROV to Changes in the Price of Reduced ANF canola Meal

Two analyses are done. The first sensitivity analysis is done using a sales volume of 225,000 metric tonnes of reduced ANF canola meal while the second one is done using a sales volume of 3,990,310 metric tones. The upper and lower bound prices are used for these sensitivity analyses. The analyses are done by varying the price of the reduced ANF canola meal captured by investors from its upper bound value of 23% of $208 to its lower bound value of 0% of $208. This is the same as varying the price from $208 to $160.

The purpose is to determine the break-even reduced ANF canola meal price that an individual biotech firm would capture or receive per each metric tonne of meal sold as well as the break-even price that would be available to the entire canola industry per metric tonne of meal sold. By this price, PBI or any prospective biotech firm taking the technology to commercialization will know the minimum expected price they must capture or receive per metric tonne of meal sold given successful commercialization of the technology. The results are presented in Figure 6.13 (Table C.13) and Figure 6.14 (Table C.14) respectively. The results show that the value of the project from the applied R&D stage (scenario 2) is far more sensitive to changes in the meal price captured than the project's value from basic R&D stage (scenario 1).

By using canola meal sales volume of 225,000 tonnes (i.e. the sales volume for the individual firm commercializing the technology) the overall value of the project is negative with NPV analysis (Figure 6.13 or Table C.13). The real option value of the project at the beginning of the basic R&D stage is greater than the initial investment cost of $743,010 required to proceed with the first year basic R&D when the price of the reduced ANF canola meal captured by potential investors at the individual firm level is 8.5% of $208 or approximately $18. This implies that the break-even price an individual private investor must receive per metric tonne of reduced ANF canola meal sold is $178. From the real option results, the project must be abandoned when the price captured by investors is below 8.5% of $208.

By using canola meal sales volume of 3,990,310 tonnes (i.e. the sales volume for the entire canola industry) the value of the project at the basic R&D stage is positive with NPV analysis when the price captured by investors is above 1.45% of $208 or $3.02 (Figure 6.14 or Table C.14). This implies that, with NPV analysis, the break-even price available to the entire canola industry per metric tonne of the reduced ANF canola meal sold is $163.02. The value of the project is negative with NPV analysis when the price captured by investors is below 1.45% of $208. The real option value of the project at the basic R&D stage is greater than the initial investment cost of $743,010 required to proceed with the first year basic R&D when the price of the reduced ANF canola meal captured by investors is at or above 0.5% of $208 or $1.01. Therefore the optimal decision would be to invest the initial $743,010 and start with the first year basic R&D. This implies that, with RO analysis, the break-even price available to the entire canola industry per metric tonne of reduced ANF canola meal sold is $161.01. The project must be abandoned when the price captured by investors is below 0.5% of $208 or $1.01.

Irrespective of the sales volume used in the analysis, the results given by varying the price of the reduced ANF canola meal captured by investors are consistent with real options predictions. From real option theory, call options become less valuable as the gross present value of the project decreases (Hull, 2002). From the results, a decrease in the price of the reduced ANF canola meal captured by investors leads to a decrease in the gross present value of the project which in turn leads to a decrease in the real options value of the project.

6.2.11 Sensitivity of NPV and ROV to Changes in the Investment Costs

Several exercise prices (i.e. R&D investment costs at each stage) are involved in this analysis. Specifically, the effect of changes in the basic R&D, applied R&D, prototype, scale-up and commercialization costs on the NPV and ROV of the project are analyzed. The exercise prices (i.e. R&D costs at each stage) are decreased to as low as 50% from the base case values using 10% increments. Subsequently the investment costs are increased to as high as 50% from the base case values using 10% increments. The results are presented in Figures 6.15 to 6.19 (Tables C.15 to C.19).

From the results the effect of changes in the different investment costs on the NPV and ROV is very similar. An increase (decrease) in the investment costs leads to a decrease (increase) in both the NPV and ROV of the project. This is shown by the negatively sloping NPV and ROV curves in Figures 6.15 to 6.19. The slopes of the curves in the graphs suggest that the NPV and ROV are more sensitive to the basic R&D cost than the other investment costs.

6.3 Summary of the Sensitivity Analysis Results

Two main categories of analysis were done. The first examined the sensitivity of the valuation results to the underlying assumptions of the model. The second addressed the sensitivity of the valuation results to some of the input variables of the model. The sensitivity analyses were done by varying the parameter under consideration while holding all the other variables of the model constant.

The summary of the first category of sensitivity analysis results are as follows. Firstly, the results show that as the dollar value of meal benefit captured by investors per metric tonne of meal sold decreased from 23% of $208 to 6% of $208 (i.e. from $48 to $12), both NPV and ROV of the project decreased. In spite of the benefit investors' capture, the overall estimate of the project's value is negative when NPV is used as the valuation model. The ROV of the entire project is zero (i.e. less than the investment cost required to proceed with the first year basic R&D or $743,010) when potential investors capture only 6% of the price of reduced ANF canola meal. The real option value of the project was found to be greater than the investment cost required to proceed with the first year basic R&D when the benefit captured by investors is at or above 8.5% of the price of improved meal. At this value of meal benefit captured, the price received per metric tonne of reduced ANF canola meal sold is $178.

Next the analysis examined the scenario when the uncertainties about the research costs are not resolved at the end of every year but rather at the end of a particular stage in the R&D timeline. Or in other words, the analysis examined the case where PBI or any potential firm commercializing the technology, is only able to fully learn about the difficulty of the research project with continuous investment until the end of a particular stage in the R&D timeline. This sensitivity analysis is done by changing the exercise pattern of the real option valuation model from a yearly exercise pattern to the case where exercise is only done at the beginning of a particular stage in the product development process. As compared with the models given by scenario *a* (i.e. the results of the real option model estimated in chapter 5), the value of managerial flexibility of the project at the start of basic research (ROV1) decreased by approximately 40% while the value at the start of applied research (ROV2) decreased by 6%. This implies that the choice of a given exercise pattern is very crucial when putting a price on managerial flexibility associated with biotech investments at the basic R&D stage.

To conclude the first category of analysis, the impact of more time steps on the valuation results is analyzed. With more time steps in the model, the estimate of the project's value given by the real option model is increased. Even though the NPV results also increased slightly, the effect is greater on the real options results. ROV1 increased from $5.41 million to $8.78 million while ROV2 increased from $18.99 million to $26 million. The percentage increase associated with ROV1 and ROV2 are 62% and 37% respectively. The results suggest that the real option value of the project is very sensitive to the number of time steps in the model. This implies that the accuracy of the real option model in providing an estimate of the value of the research project is improved with more time steps in model.

The results of the second category of sensitivity analysis show that variation in the chosen input variables of the models estimated in chapter 5 (i.e. scenario *a*) significantly exerts a differential impact on the NPV and ROV of the project. The value of the research project estimated is positive with NPV analysis when the basic R&D is above 33%. Similarly, the value of the research project estimated is positive with NPV analysis when the applied R&D is above 67%. Also the value of the research project estimated is positive with NPV analysis when prototype and scale-up probabilities of success are above 84% and 95% respectively. The value of the research project at the basic R&D stage is negative with NPV analysis as the probabilities are decreased together from their base case values to as low as 22%. However, the real option value of the project at the basic R&D stage is greater than $743,010 when all the probabilities of success are decreased together by 14% from their base case values. This implies that when the probabilities of success for basic R&D, applied R&D, prototype and scale-up stages are equal to or greater than 16%, 46%, 61% and 71% respectively, the real option value of the project is greater than the initial investment cost required to start with the first year of basic R&D. Below these probabilities of success values, the project must be abandoned.

The value of the research project estimated at the beginning of the basic R&D stage is positive with NPV analysis when the risk-free rate, discount rate, sales volume, basic R&D cost and applied R&D cost are above 5.1%, 18%, 251,146 metric tones, $545,439 and $273,283 respectively. When these input variables are below these values, the estimated value of the canola research project is negative with NPV analysis. The results show that the estimated value of the research project is negative with NPV analysis when the prototype and scale-up R&D cost respectively are either decreased to as low as 50% or increased to as high as 50% from the base case values.

The real option value of the project is greater than the initial investment cost required to proceed with the first year basic or applied R&D (i.e. $743,010 or $500,000) when the technological probabilities of success, price volatility, risk-free rate, discount rate, yearly canola meal sales volume and R&D investment costs are varied over the chosen range of values. The real option value at the basic R&D stage of the project is greater than the initial investment cost of $743,010 when investors capture 8.5% of the price of reduced ANF canola meal (individual level) or 1.45% of the price of reduced ANF canola meal (industry level).

In general, the analysis shows that both the NPV and ROV of the project have a positive relationship with all the technological probabilities of success (risks), the risk-free rate, price of reduced ANF meal as well as the sales volume parameters. It however has a negative relationship with the discount rate and all the exercise prices associated with the project. The volatility associated with price has no relationship with NPV however it has an overall positive relationship with the ROV of the project. The analysis has shown that the RO approach seems to be a more appropriate approach than the traditional NPV method in valuing agricultural biotechnology investments. It is assumed that farmers in the pork, poultry and aquaculture industry may shift from the use of soy meal to the improved canola meal, if the reduced ANF canola meal is commercialized.

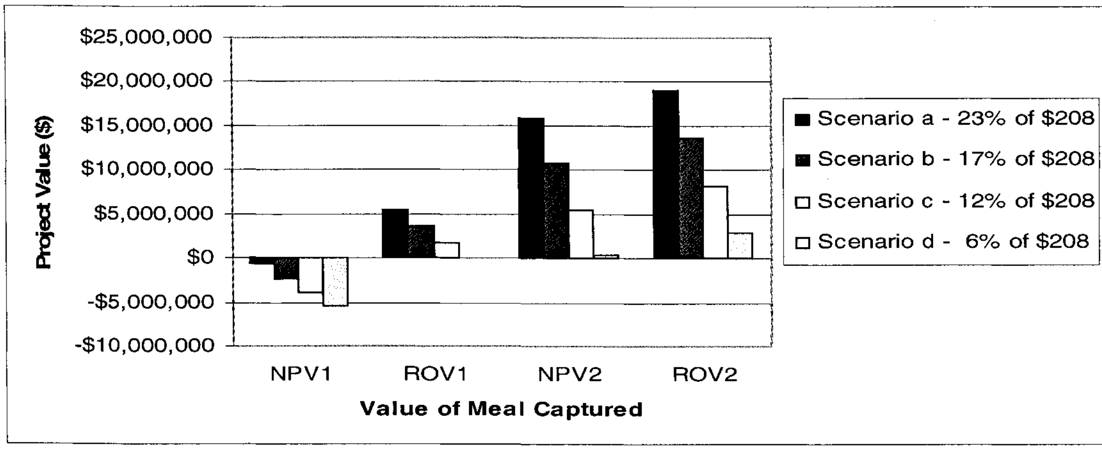
6.4 Tables for Chapter 6

Table 6.1 Values of Input Variables above which the Project is Positive with NPV Analysis

Variable	Value at which to invest now	NPV1
Basic R&D probability of success	33%	$0
Applied R&D probability of success	67%	$0
Prototype probability of success	84%	$0
Scale-up probability of success	95%	$0
Risk-free rate	5.1%	$0
Sales volume	251,146 metric tonnes	$0
Risk-adjusted discount rate	18%	$0
Basic R&D cost	$545,439	$0
Applied R&D cost	$273,283	$0

6.5 Figures for Chapter 6

Figure 6.1 Sensitivity of NPV and ROV to Changes in the Reduced ANF Canola Meal Price Received by Investors

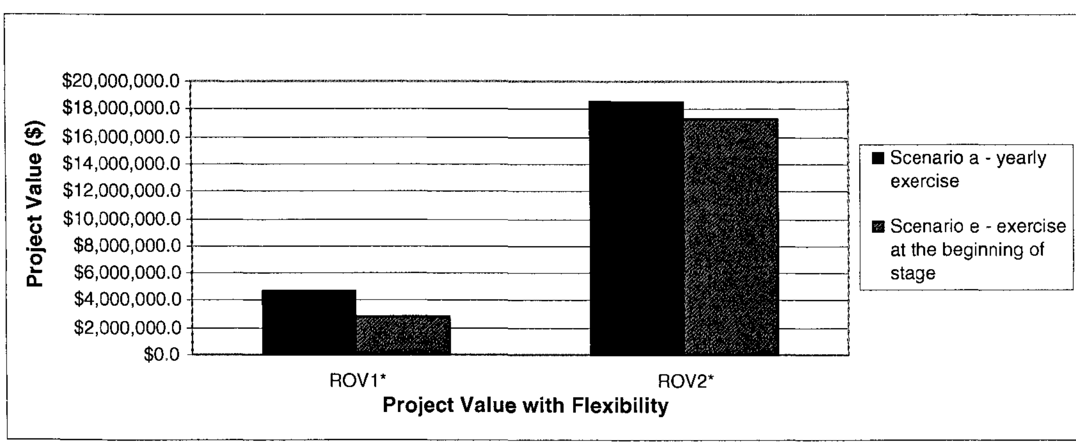


Note: Sales volume in metric tonnes = 225,000.
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

NPV1 = Project value without flexibility assuming PBI will take the innovation from basic R&D to market
NPV2 = Project value without flexibility when investment in basic R&D is assumed to be sunk and a collaborating firm takes the innovation from the applied R&D stage all the way to market launch.

ROV1 = Project value with flexibility assuming PBI will take the innovation from basic R&D to market
ROV2 = Project value with flexibility when investment in basic R&D is assumed to be sunk and a collaborating takes the innovation from the applied R&D stage all the way to market launch.

Figure 6.2 Sensitivity of ROV to Different Exercise Patterns

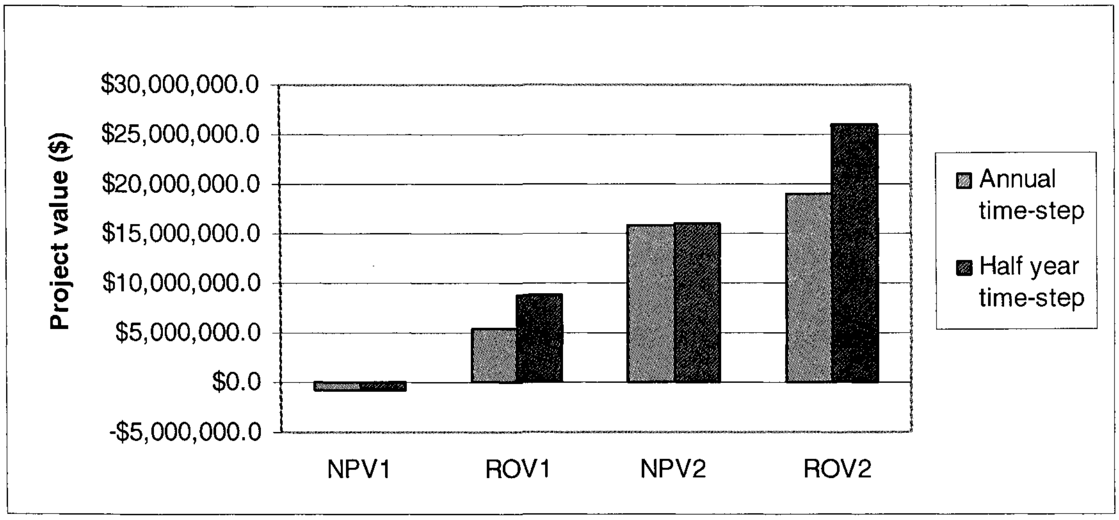


Note: ROV1* and ROV2*refers to the value of managerial flexibility estimated at time period t=0. Invest in the next R&D stage if ROV1* > $0; ROV2 > $0, otherwise abandon.

Scenario a = PBI is assumed to exercise its call option on the next stage or make abandonment decision at the beginning of each year with the information acquired from completing the previous year's investment.

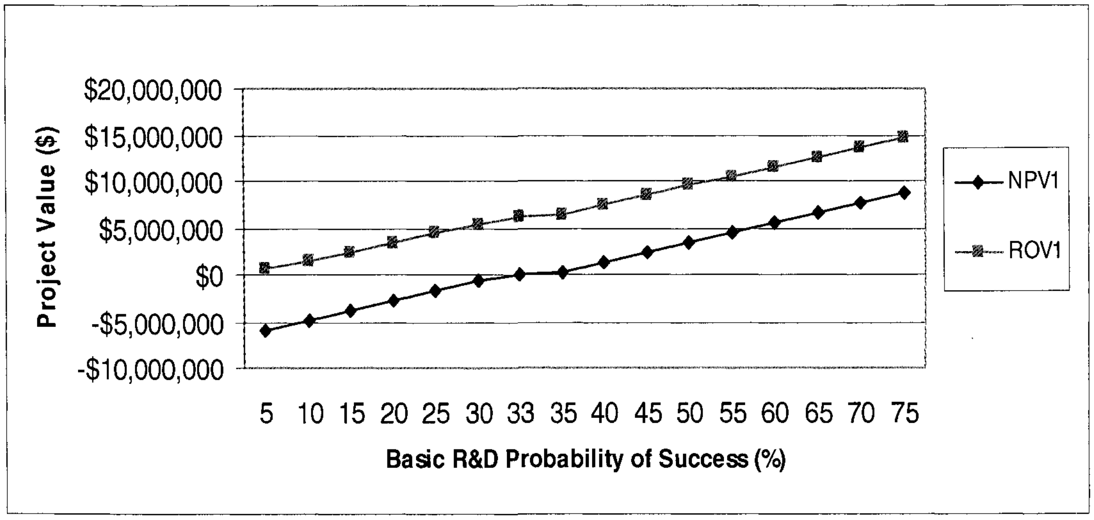
Scenario e = PBI is assumed to exercise its call option on the next stage or make abandonment decision only at the beginning of each stage with the information acquired from the completion of the previous stage's investment.

Figure 6.3 Sensitivity of NPV and ROV to More Time Steps



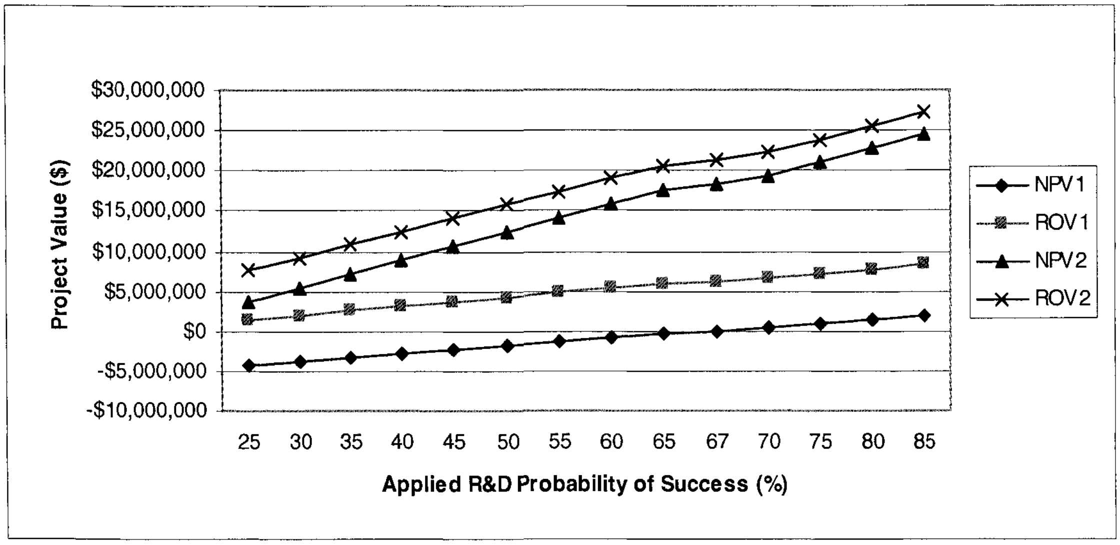
Number of times the option is exercised is the same.
Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Figure 6.4 Sensitivity of NPV and ROV to Changes in the Probability of Success Associated with the Basic R&D Stage



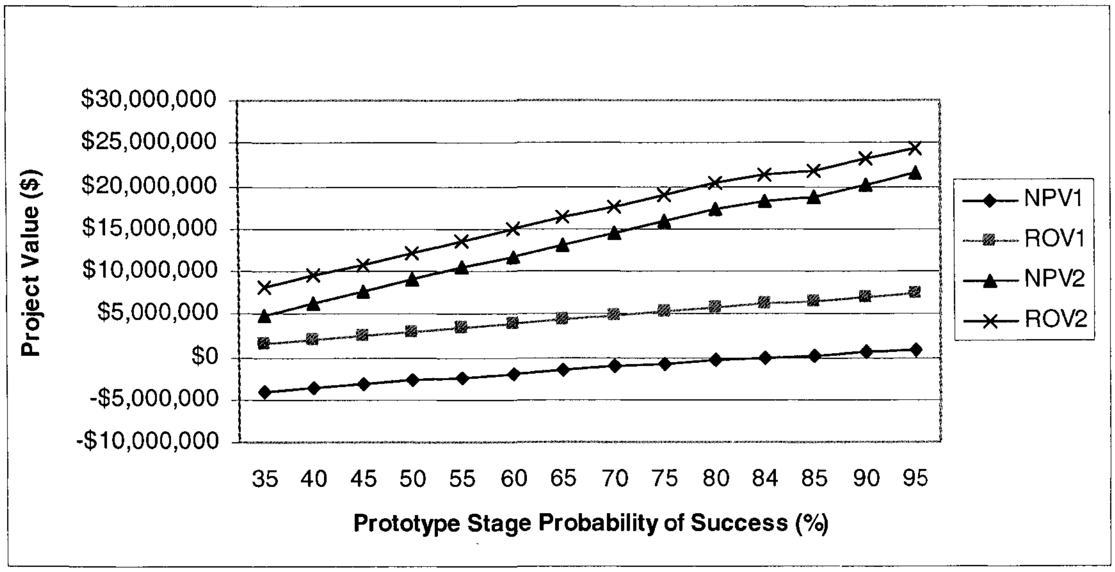
Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Figure 6.5 Sensitivity of NPV and ROV to Changes in the Probability of Success Associated with the Applied R&D Stage



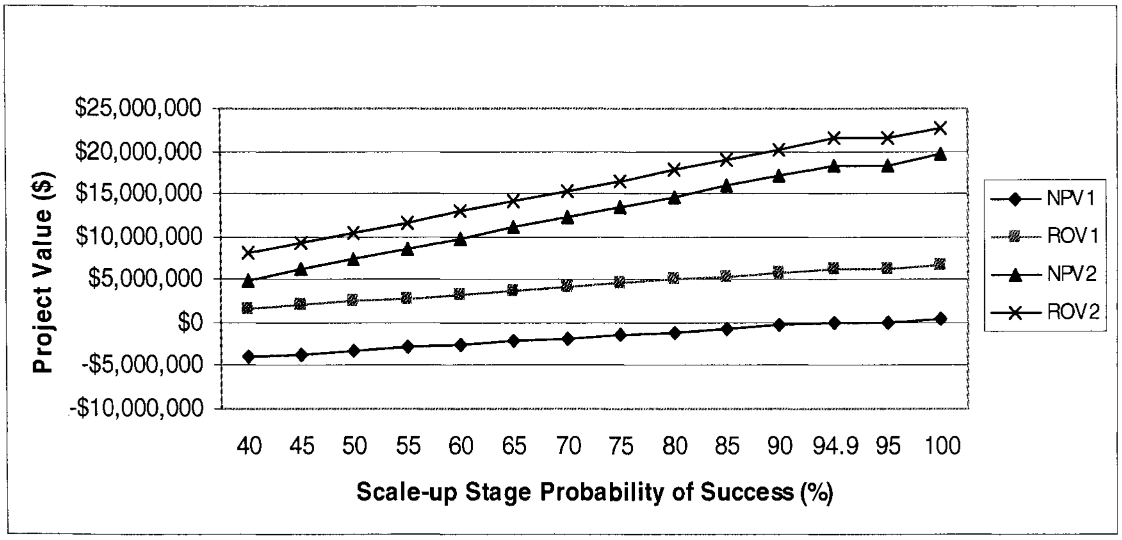
Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Figure 6.6 Sensitivity of NPV and ROV to Changes in the Probability of Success Associated with the Prototype Stage



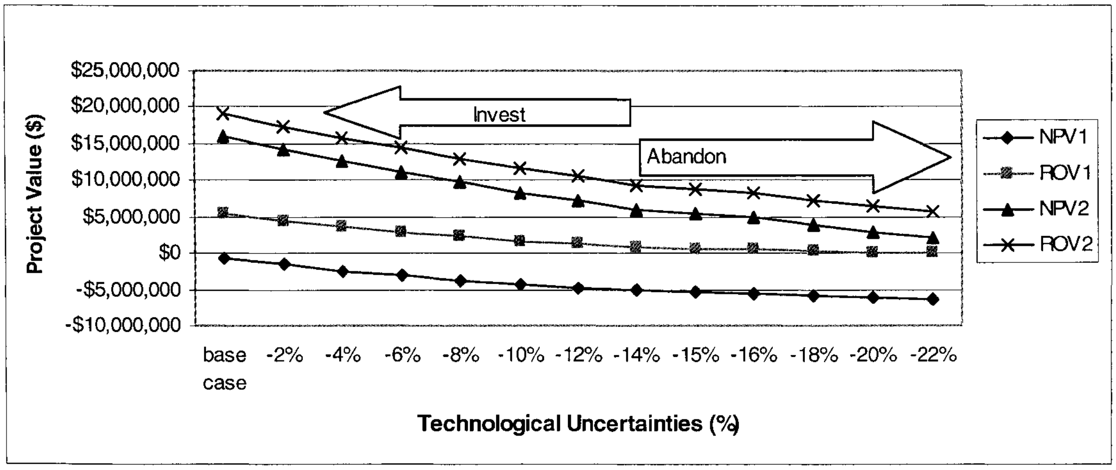
Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Figure 6.7 Sensitivity of NPV and ROV to Changes in the Probability of Success Associated with the Scale-up Stage



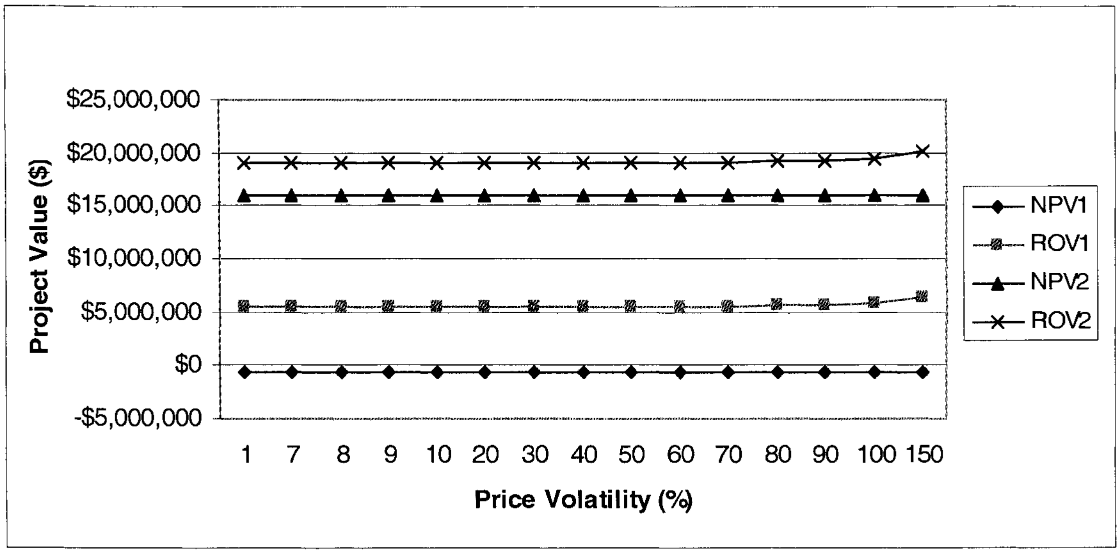
Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Figure 6.8 Sensitivity of NPV and ROV to a Decrease in All Technological Probabilities of Success using Increments of 2%



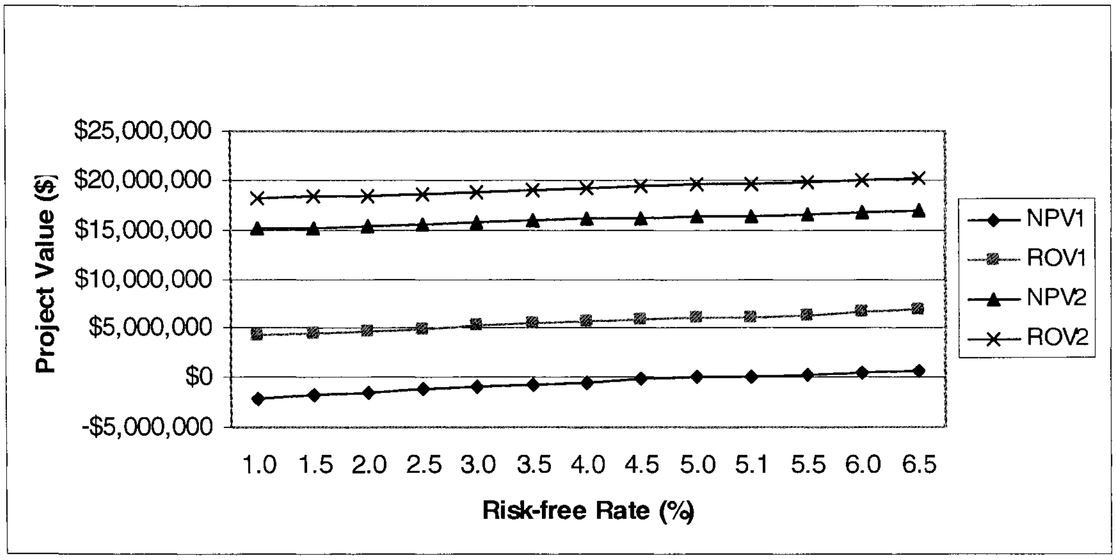
Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Figure 6.9 Sensitivity of NPV and ROV to Changes in Price Volatility



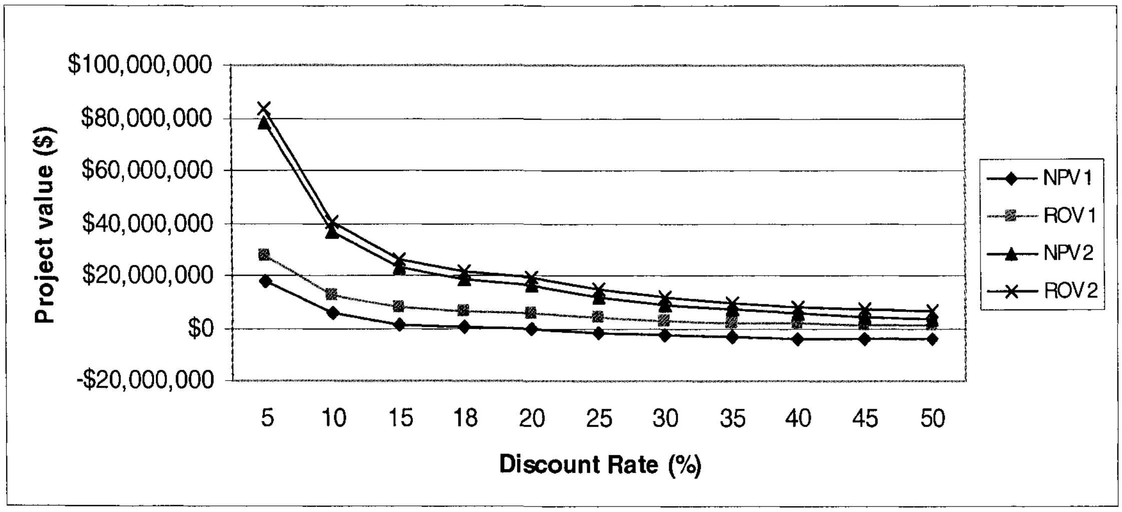
Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Figure 6.10 Sensitivity of NPV and ROV to Changes in the Risk-free Rate



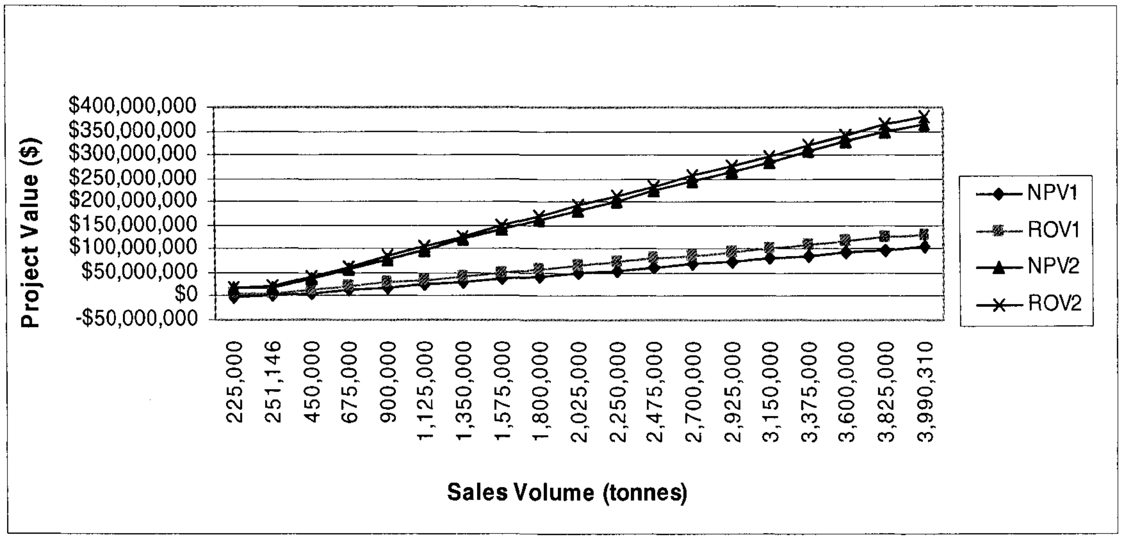
Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Figure 6.11 Sensitivity of NPV and ROV to Changes in the Discount Rate



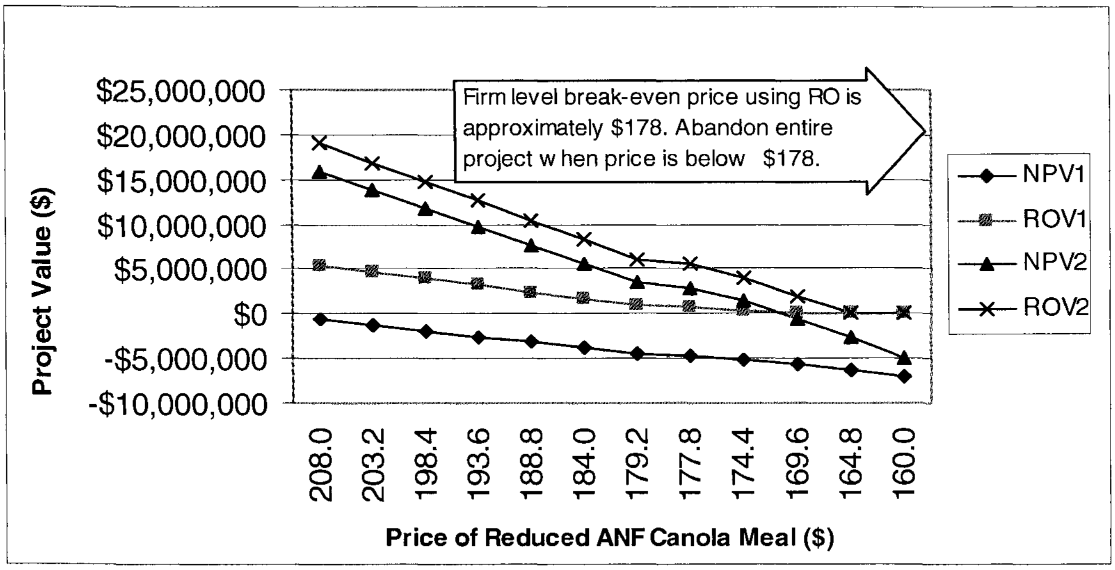
Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Figure 6.12 Sensitivity of NPV and ROV to Changes in the Sales Volume of Reduced ANF Canola Meal



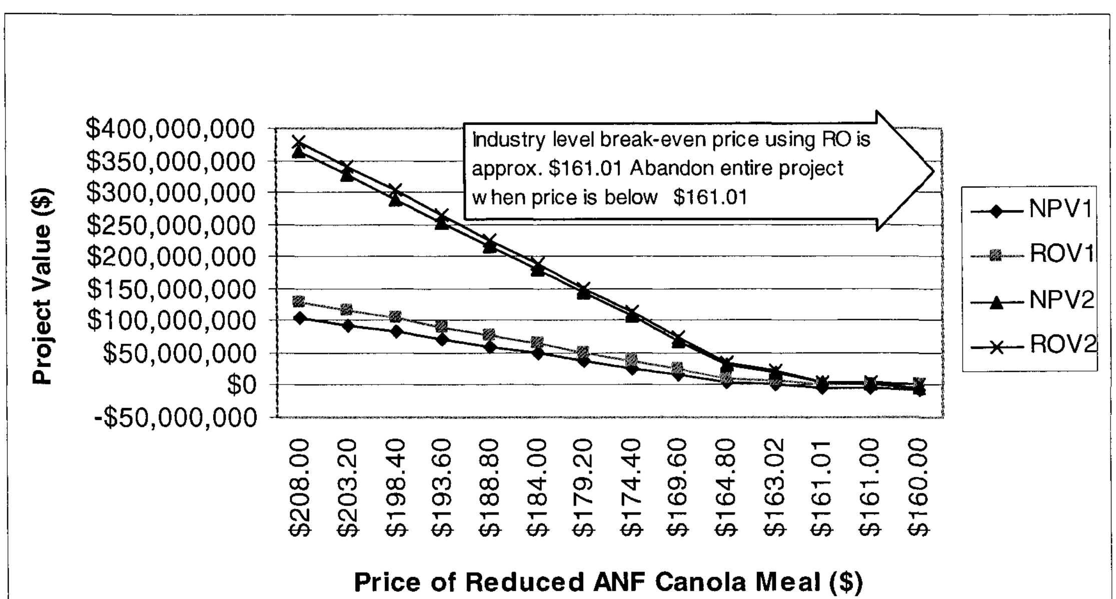
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Figure 6.13 Sensitivity of NPV and ROV to Changes in the Price of Reduced ANF Canola Meal (Firm level break-even price)



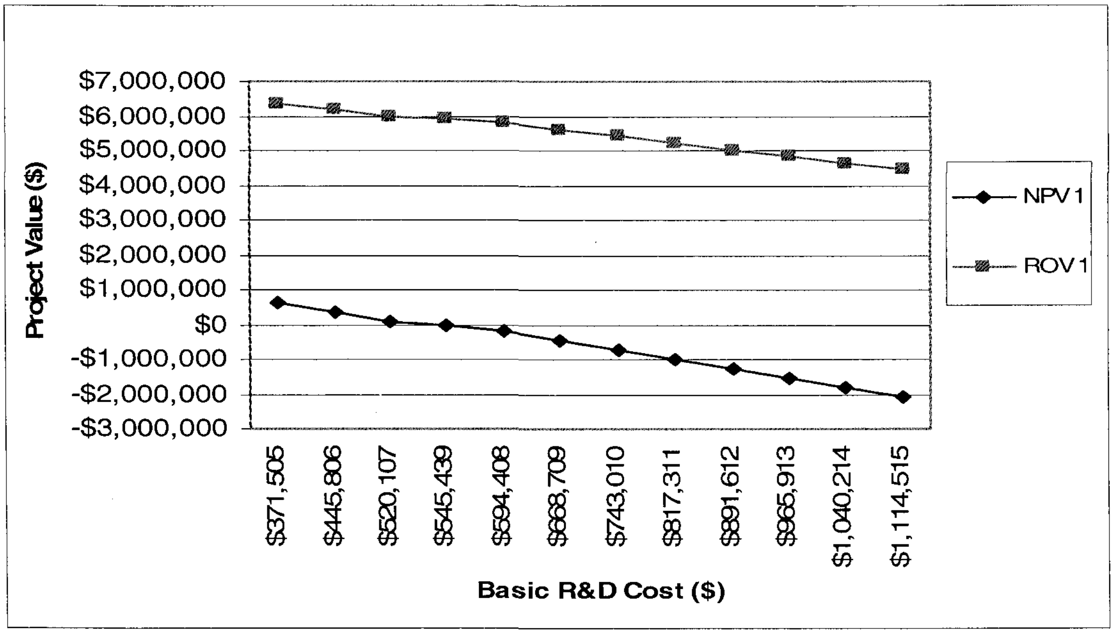
Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Figure 6.14 Sensitivity of NPV and ROV to Changes in the Price of Reduced ANF Canola Meal (Industry level break-even price)



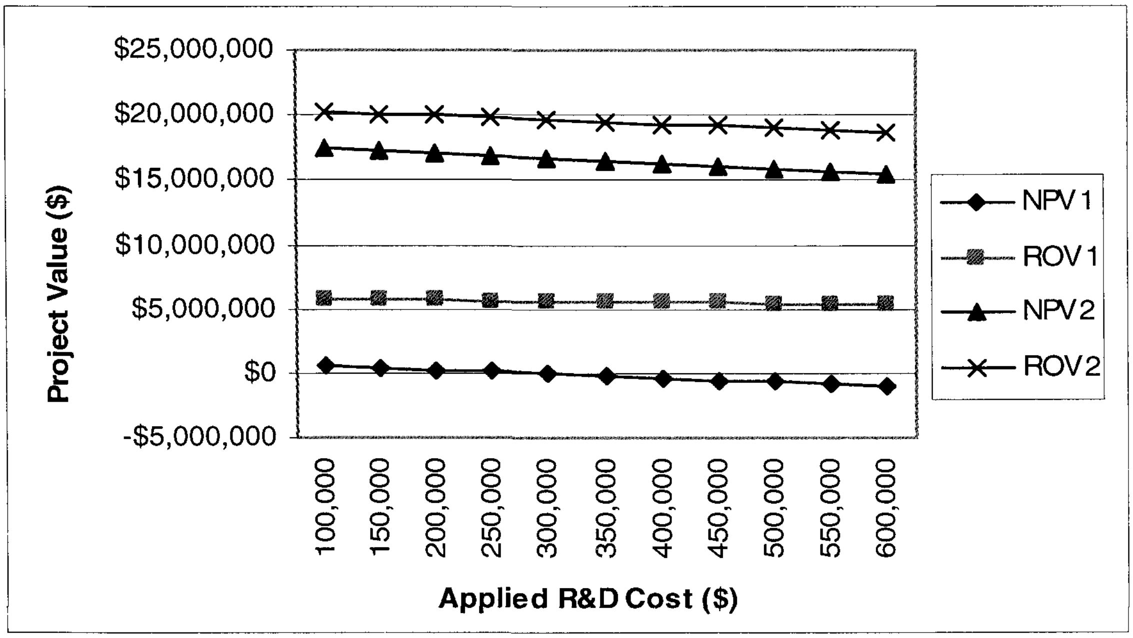
Sales volume in metric tonne = 3,990,310
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Figure 6.15 Sensitivity of NPV and ROV to Changes in Basic R&D Cost



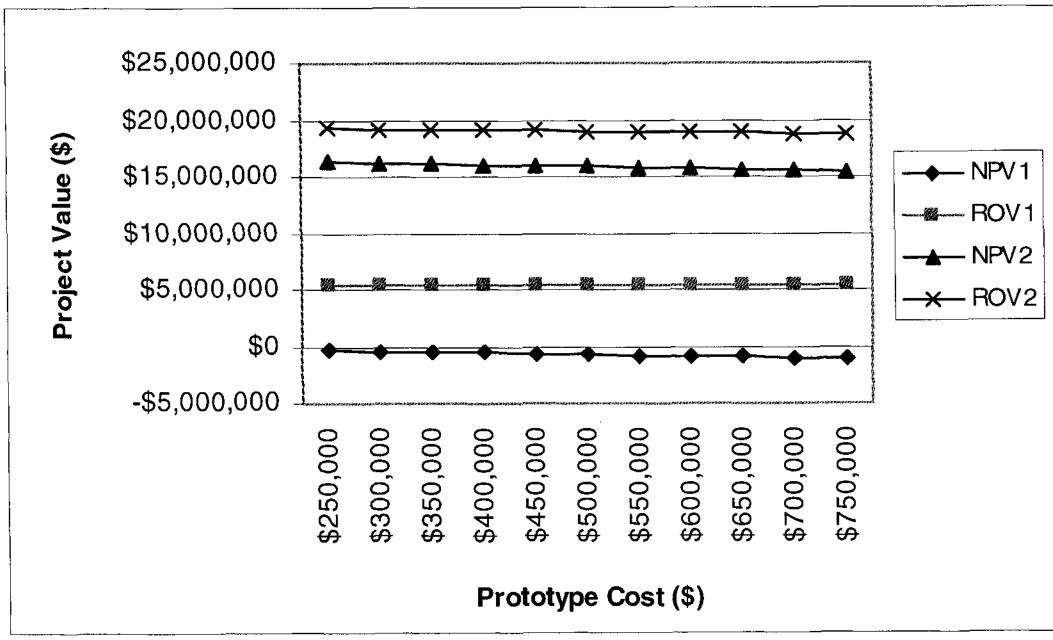
Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Figure 6.16 Sensitivity of NPV and ROV to Changes in Applied R&D Cost



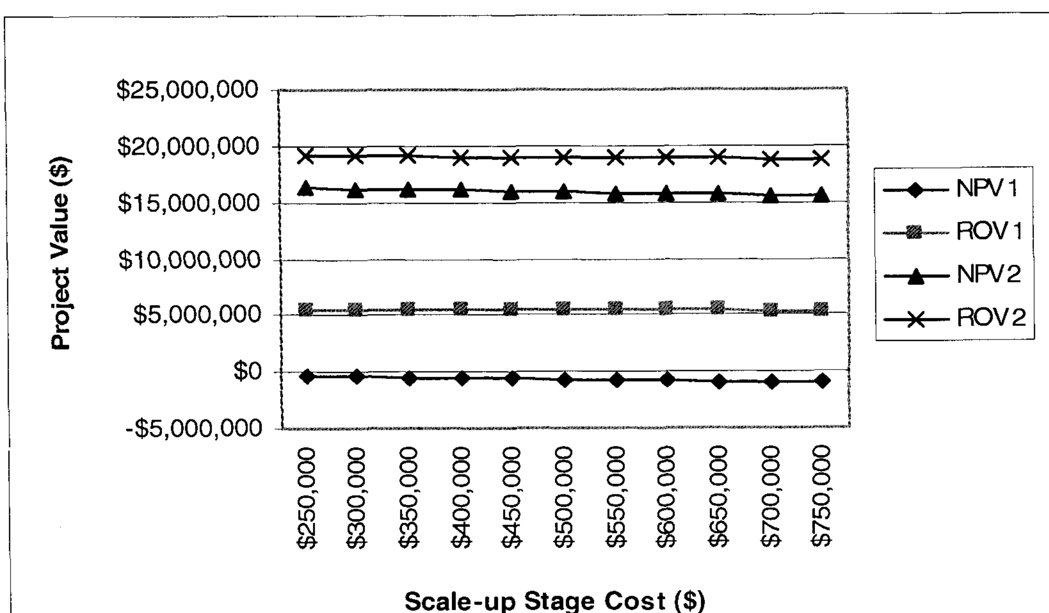
Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Figure 6.17 Sensitivity of NPV and ROV to Changes in Prototype Cost



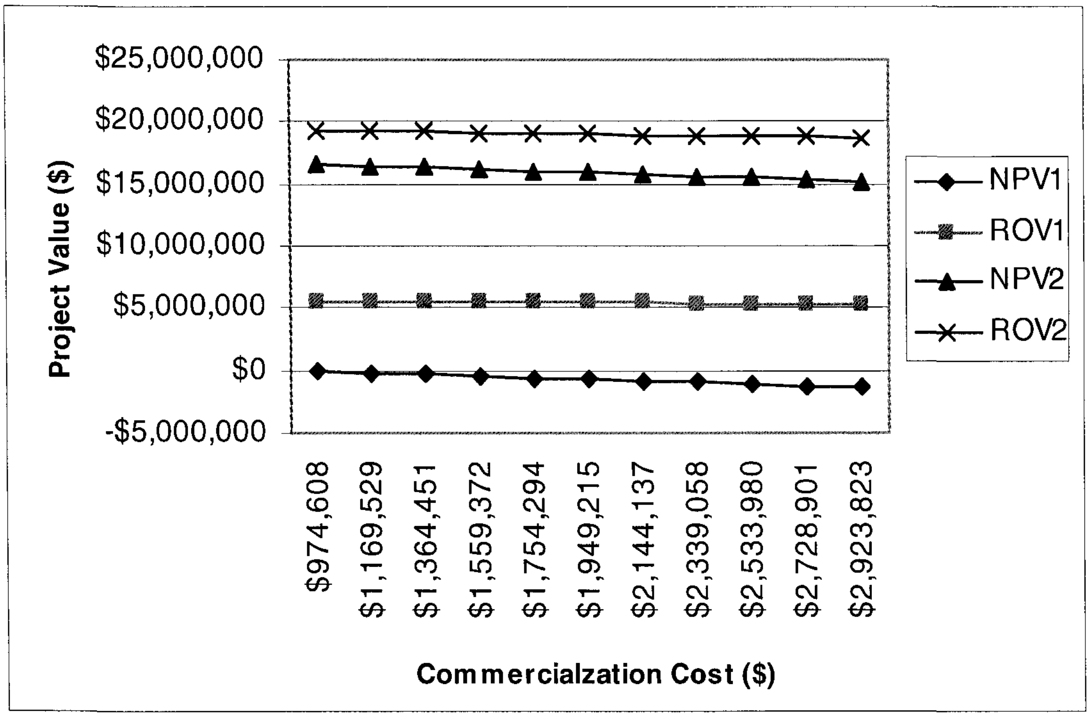
Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Figure 6.18 Sensitivity of NPV and ROV to Changes in Scale-up Cost



Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Figure 6.19 Sensitivity of NPV and ROV to Changes in Commercialization Cost



Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

CHAPTER 7 REAL OPTION EVALUATION AND CONCLUSION

This final chapter addresses the conclusions and key issues of this thesis. First the NPV and RO approaches are evaluated based on the analyses. Secondly, the implications of the thesis are addressed. This discussion relates to the case study and how it impacts on policies affecting the overall canola and canola meal industry in Western Canada. Thirdly, key issues arising from the thesis are discussed. The discussion addresses the suitability of the NPV and RO approaches for valuing agricultural biotechnology R&D investments. Furthermore, the potential challenges of using the valuation techniques are discussed. A suggestion concerning when to use these models as well as when they are not appropriate is included in the discussion. Finally, the limitations of the thesis as well as the direction for future studies are addressed.

7.1 Evaluation of NPV and RO Analyses

The main objectives of this thesis were to evaluate the feasibility of the application of real options to agricultural biotechnology research projects and provide recommendations about the value of strategic managerial decision-making using different models. Specifically, the NPV and RO approaches were used to evaluate the investment decision associated with developing a platform technology which when incorporated into canola seed in Canada will yield canola meal with reduced anti-nutritional factors. The technology aims at improving the functional and nutritional composition of canola meal which may ultimately open up new markets in the pork, poultry and aquaculture industry.

Biotechnology projects are characterized by a high level of future risk as well as irreversibility of their staged investment expenditures. This future risk influencing the present value of R&D projects and in particular this canola meal enhancing project was composed of technological and product price risks. Management subjective estimates concerning technological risks were used. Price risk was estimated using historical data. The two risks (i.e. technological and price) were resolved simultaneously using the quadranomial approach.

The NPV of the project was estimated using the certainty equivalent method. This method estimates certainty equivalent cash flows which are discounted at the risk free rate. The certainty equivalent cash flows were estimated using risk neutral probabilities. The NPV of the research project at the basic R&D stage was negative (i.e. -$0.73 million) suggesting that PBI should not have undertaken the project. On the contrary the project is still underway, suggesting that the management of PBI envision some specific value of the project that the NPV model was not able capture. Generally the NPV model does not account for the value of managerial flexibility.

The NPV of the project was also estimated at the beginning of applied research, prototype and scale-up stages respectively upon the assumption that investment expenditures in prior stages are sunk costs. The value of the project determined for these stages were all positive (Table 5.7) indicating that the project is worthwhile if earlier stages are successfully completed.

A specialized version of the multiplicative binomial option pricing model, the quadranomial approach was used to evaluate the research project as a series of compound call options. This model accounts for the value of managerial flexibility as well as the sequential nature of R&D projects. Though the NPV of the overall research project was negative, the real option model increased the estimate of the project's value thus changed the investment decision from abandon to invest in the canola R&D project.

The ROV of the research project at the beginning of the basic R&D stage was $5.41 million. This means that PBI should make the initial investment of $743,010 and proceed with the first year of basic R&D. It also means that if there is additional research to be done to make the project viable PBI could spend up to $5.41 million less the initial investment cost of $743,010 required to proceed to the next R&D stage. Again, the ROV of the project at the beginning of the applied research, prototype and scale-up stages respectively on the assumption that investment expenditures in prior stages are sunk were estimated. The values determined were all greater than the required investment cost of $500,000 needed to proceed to the next R&D stages respectively (Table 5.7). Since the real options value of the project estimated at the beginning of each R&D stage was greater than the investments costs required to proceed to the next R&D stage, once the project is started, PBI should continue to invest. This recommendation reflects what PBI is actually doing presently.

Since the investment decision given by the NPV and real option models from the applied R&D stage is the same, the NPV approach may be favoured over the real options approach when valuing R&D type of investments from the applied research stage through to the commercialization stage. This is because the NPV approach is relatively simple as compared with the real options approach.

Sensitivity analyses of the valuation results to changes in the underlying assumptions and input variables of the model were performed. The results indicate that when the reduced ANF canola meal is not completely substitutable for soybean meal, the value of the project at the basic R&D stage is negative with NPV analysis irrespective of the dollar value of meal benefit investors' capture. The sales volume used is 225,000 metric tonnes. The real option value of the project at the basic R&D stage, however, was found to be greater than $743,010 when the benefit captured by investors is at or above 8.5% of the price of improved meal. This implies that the break-even price an individual private investor must receive per metric tonne of reduced ANF canola meal sold with RO analysis is $178. By using canola meal sales volume of 3,990,310 tonnes (i.e. the sales volume for the entire canola industry) the value of the project at the basic R&D stage is positive with NPV analysis when the benefit of the reduced ANF canola meal captured by investors is above 1.45% of the price of improved meal. The real option value of the project at the basic R&D stage is greater than $743,010 when the benefit captured by investors is at or above 0.5% of the price of improved meal. Thus the break-even prices available to the entire canola industry per metric tonne of the reduced ANF canola meal sold with NPV and RO analyses are $163.02 and $161.01 respectively.

By analyzing the scenario when the uncertainties about the research costs are not resolved at the end of every year but rather at the end of a particular stage in the R&D timeline (i.e. changing the exercise pattern from yearly to exercise only at the beginning of a stage), the value of managerial flexibility at the start of basic research decreased by approximately 40% (i.e. from $4.66 million to $2.8 million) while the value at the start of applied research decreased by 9% (i.e. from $18.49 million to $17.31 million). This result indicate that the time it takes to resolve the uncertainties about the research costs is very crucial when putting a price on managerial flexibility associated with biotech investments at the basic R&D stage. The sensitivity results also indicate that with more time steps in the model, the accuracy of the real option model in providing an estimate of the value of the research project is improved.

With respect to the second category of sensitivity analysis the results indicate that by holding all other variables constant, the NPV and ROV of the project decreased with a decrease in all the technological probabilities of success, the risk-free rate, price of reduced ANF canola meal as well as the sales volume parameters. The NPV, however, increased with a decrease in the discount rate and all the exercise prices associated with the research project. The volatility associated with price has no relationship with NPV when the discount rate is kept constant however it has an overall positive relationship with RO value of the project.

When all the probabilities are decreased together from their base case values to as low as 22%, the value of the research project at the basic R&D stage is negative with NPV analysis. The real option value at the basic R&D stage, however, was found to be greater than $743,010. Thus the threshold probabilities of success for basic R&D, applied R&D, prototype and scale-up stages given by the real option model for this canola research project are 16%, 46%, 61% and 71% respectively. When the probabilities are below these threshold values, the project should be abandoned. The NPV of the research project was found to be positive when the basic R&D, applied R&D prototype and scale-up probabilities of success, the risk-free rate, discount rate, sales volume, basic R&D cost and applied R&D cost are above 33%, 67%, 84%, 95%, 5.1%, 18%, 251,146 metric tones, $545,439 and $273,283 respectively. When these input variables are below these values, the estimated value of the canola research project is negative with NPV analysis.

One common challenge with the two approaches concerns the determination of a perpetuity value associated with the project once the product is commercialized. This required the use of a discount rate. The analyses used subjective estimates from experts. Also, using the quadranomial approach calls for the estimation of quadranomial risk neutral probabilities. The RO approach requires that the modeler interact with management before any meaningful options associated with a particular investment project can be identified.

7.2 Implications

Commercializing PBI's canola meal enhancing technology has implications on the economy of western Canada. The oilseeds sector in Canada is a major contributor to the economy of Canada in terms of value-added and employment (Agriculture and Agri-Food Canada, 2004). Long-run economic growth and development depend heavily on productivity, which in turn relies on new knowledge and on innovation created by research and development. The type of modeling approach used to evaluate R&D investments may have consequences on investment decisions.

The analysis has shown that the canola R&D project may be feasible with RO analysis. This canola project would be of high significance to western Canada. Canada is a large net exporter of canola meal and a large net importer of soy meal, into western Canada (Agriculture and Agri-Food Canada, 2004). In 2003, slightly over $250 million worth of protein meals was exported by Canada (Agriculture and Agri-Food Canada, 2004). Out of this, canola meal exports amounted to $226 million. By contrast, for the 2003 calendar year Canada imported $328 million worth of protein meal, mostly soy meal valued at $325 million (Agriculture and Agri-Food Canada, 2004). In 2003, canola meal accounted for 19% (i.e. 546,000 tonnes) of total domestic use of vegetable protein meals compared with 80% (i.e. 2,327,000 tonnes) for soymeal. The total domestic use of vegetable protein meal in 2003 is 2,919,000 tonnes.

Given the successful development and commercialization of the reduced ANF canola meal, farmers in the pork, poultry and aquaculture industry may shift from the use of soy meal to the improved canola meal. This might lead to an increase in the domestic use of canola meal which eventually will be of great benefit to the entire canola industry. The value of the canola industry may be increased as a result of the increased value of the meal.

Even though the analysis has shown that the canola R&D project has great value, Hinther, (2004) indicated that PBI has not been able to attract potential private investors to commercialize the project. This may be attributed to a number of reasons. One possible reason is that the cost of taking PBI's technology from basic R&D to commercialization may be high relative to other related research projects. For example MCN BioProducts Inc. in Saskatoon has developed a lead processing technology to convert canola meal into multiple product streams such as protein concentrates, customized fiber protein products and other co-products tailored to maximize value in their respective markets and generate significant value in excess of that derived from canola meal. MCN's technology is currently entering the commercialization phase. If MCN and PBI's research projects are mutually exclusive and given the fact that R&D funds are limited, it makes economic sense to invest in the commercialization of the technology that will yield a higher value.

Another possible reason is that private firms may not know how much of the rent they would capture once the technology is fully commercialized. Even though the existence of property rights would allow any biotechnology firm that is interested in commercializing the canola meal enhancing technology to capture a greater share of the value created through research from the applied R&D stage, the negotiation and enforcement of contracts to manage this property right is costly. This high cost may potentially reduce the amount of benefit that firms would capture. Also, if the reduced ANF canola meal is not completely substitutable for soybean meal, it makes the private firm's decision process more difficult.

7.3 Key Issues

The results of this thesis have shown that a considerable difference exists between the overall estimated NPV and ROV of the biotechnology R&D project. Therefore, assessing and quantifying how much an agricultural biotech investment from the basic R&D stage is worth using only the static NPV is limiting. NPV method does not capture the value of managerial flexibility. The real option analyses have shown that managerial flexibility has value. When flexibility was incorporated into the analysis the real option results increased significantly. As such managerial flexibility must be incorporated into the valuation framework when analyzing biotechnology R&D investments.

One important finding from the analyses was that when the research project has not successfully passed the basic R&D stage (i.e. probability of success surrounding the project is low or risk is high), there is a significant difference between the estimated NPV and ROV of the research project. Once the research project has successfully passed the basic R&D stage (i.e. probability of success surrounding the project becomes high or the risk is reduced) the results of the NPV and RO models yield the same investment decision for this case study. Thus we conclude that the real option approach is especially useful to value high risk agricultural biotechnology R&D projects. The basis for investing in such projects depends on their RO value. This conclusion applies to other strategic high risk public R&D projects that require large dollar investments. The NPV approach on the other hand may be favoured over the real options approach when valuing R&D type of investments from the applied research stage. This is because the NPV approach is relatively easier to estimate as compared with the real options approach.

This thesis contributes to the existing body of literature regarding applications of real options in the following ways.

1. It has demonstrated that the RO approach could be used to value agricultural biotech R&D investment projects.
2. It has shown that the RO models have the potential to improve the standard discounted cash flow analysis. The RO approach provides a set of guidelines as to the investment policy. By examining the payoff values at each node or at the end of each stage an investor can determine whether it is optimal to continue to invest, wait or abandon the project midstream. The NPV approach does not provide guidelines on when to invest, wait, abandon etc.
3. It has demonstrated that by keeping the key risks that affect the value of R&D projects separate, the quadranomial approach discussed in Copeland and Antikarov, (2003) could be applied to appropriately value the sequential stages associated with high risk research projects.
4. It has demonstrated that when the risk surrounding the research project is not too high, the NPV model is as good as the RO model.
5. Also, it explains the staged investment approach used by venture capitalist to finance high risk technology investments.
6. It has demonstrated how to value public policy and R&D investment projects.
7. The quadranomial approach used in this thesis would serve as a guide for further studies.

7.4 Limitations and Direction for Future Studies

This thesis valued a public biotechnology R&D investment project. Certain key assumptions were made in order to quantitatively evaluate the project. This is because the data available were limited. As such the valuation results have the following limitations.

7.4.1 Limitation of Analyses

The first limitation of the NPV and RO analyses relates to the exercise prices used. For simplicity the analysis assumed that the investments costs for the various stages were certain and independent of the economy thus they were discounted at the risk free rate. Secondly, the discount rate used to determine the perpetuity associated with the project may also not be exact. Thirdly the two key risks (i.e. technological and price) that affects the value of the project were assumed to be uncorrelated with each other and that each risk follows a geometric Brownian motion stochastic process. Several other stochastic processes for example mean reversion or Poisson could be modeled. In the biotechnology industry, investors may respond positively when a particular biotechnology product is approved by the regulatory agency. Where the biotechnology product is listed on the stock market, a positive premium is placed on the firm's stock price. Thus it is possible that at the minimum, the scale-up technological risk may be correlated with price risk. Also it is possible that the technological risks may be correlated with each other, for instance, basic R&D risk may be correlated with applied R&D risk, prototype or scale-up risk. Therefore the assumption that technological risk is uncorrelated with price risk is a limitation of the models used in the analysis. Fourthly, the value of the project computed at the start of the applied R&D, prototype and scale-up stages respectively did not account for royalty payments due PBI. Thus the estimated value of the project at the beginning a particular stage in the R&D timeline may not reflect the actual value.

Overall, the sensitivity analyses conducted in this thesis are based on changing one variable at a time and examining its impact on the NPV and ROV, holding all the other variables constant. This ignores the impact of a combination of variables. The changes were done arbitrarily. They were not based on the uncertainty associated with the estimated probability distributions of these variables. This approach was used for simplicity. Thus it may not reflect what pertains for most real high risk new technology ventures.

7.4.2 Future Research

Future studies should apply the valuation models used in this thesis to a privately-owned agricultural biotech R&D investment project and determine how that will impact on the investment decisions of the project. The case study evaluated in this thesis did not take into account royalties or technology use fees that are supposed to be charged on the sale of the improved ANF canola seed once commercialized. A portion of this is supposed to flow back to PBI. Therefore future research should investigate the impact of royalties on the overall investment decision of the project. Also, the exercise prices should be made stochastic to see how that impacts on the NPV and RO results. This case study assumed that the key risks that affect the value of the canola research project are not correlated. Future research should explore the case where the key risks that affect the value of biotechnology projects are correlated. Also, the case study evaluated in this thesis assumed that the key risks follow a geometric Brownian motion stochastic process. Future research should use a mean reverting stochastic process to determine how that will impact on the investment decisions of the project. Another consideration would be to evaluate flexible model alternatives to the binomial model such as the least square Monte Carlo option valuation approach.

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APPENDIX A

Capital Asset Pricing Model (CAPM)

The Capital Asset Pricing Model is developed by Sharpe, (1964). This section provides the intuition behind the approach. The CAPM is an equilibrium asset pricing theory that shows that equilibrium rates of expected return on all risky assets are a function of their covariance with the market portfolio. Under the assumption of homogeneous expectation, all individuals hold the market portfolio thus CAPM assumes that a portfolio's expected return is dependent solely on its systematic risk, referred to as beta (Ross et al., 1999). The model posits that the expected return of an asset (or derivative) equals the risk-free rate plus a measure of the assets non-diversifiable risk (beta) multiplied by the market-wide risk premium (i.e. difference between the expected return on market and risk-free rate). Algebraically, the CAPM equation is given as:

$$E(R_p) = R_f + \beta\left[E(R_m) - R_f\right],$$

where:

$E(R_p)$ = the expected returns on any efficient portfolio

R_f = the risk free rate

$E(R_m)$ = the expected returns from the market portfolio

β = beta of the security

The characteristics of an asset beta are similar to that of a covariance. This is because by definition, $\beta = \dfrac{Cov(R_m, R_p)}{VarR_m}$ thus it measures the degree to which an asset's returns co-move with the returns on the market. The beta variable shows how a project risk is related to the market risk. The CAPM essentially concludes that only the systematic risk affects the market price of the asset.

APPENDIX B

Adjusting the Price of Reduced ANF Canola Meal on Crude Protein Basis

The estimated average soybean meal price is CAN $293 per metric tonne. This price is assumed to be the cost of crude protein (C.P) in the soybean meal. Soybean meal has 48% C.P but canola meal has 34% C.P. Simple proportion is used to adjust the estimated average soybean meal price on the basis of C.P content. This is represented as:

$$\frac{34}{48} \times \$293 = \$208$$

Thus the average price of soybean meal with 34% C.P determined is CAN $208 per metric tonne.

APPENDIX C

Table C.1 Results of the Sensitivity of NPV and ROV to Changes in the Potential Benefit Received by Investors

Scenario 1 (Basic R&D)	Assumption	Potential benefit captured	Other cost	NPV1	ROV1	% change NPV1	% change ROV1
a	100% of 48	23% of price	0.77 of revenue	-$725,692	$5,407,598	0.0	0.0
b	75% of $48	17% of price	0.83 of revenue	-$2,286,919	$2,810,341	-215.1	-39.8
c	50% of 48	12% of price	0.88 of revenue	-$3,848,145	$956,093	-68.3	-66.0
d	25% of $48	6% of price	0.94 of revenue	-$5,409,372	$0	-40.6	-100.0
Scenario 2 (Applied R&D)	**Assumption**	**Proportion of price received**	**Other cost**	**NPV2**	**ROV2**	**% change NPV2**	**% change ROV2**
a	100% of 48	23% of price	0.77 of revenue	$15,899,395	$18,986,957	0.0	0.0
b	75% of $48	17% of price	0.83 of revenue	$10,707,752	$13,113,606	-32.7	-29.1
c	50% of 48	12% of price	0.88 of revenue	$5,516,109	$7,740,256	-48.5	-41.0
d	25% of $48	6% of price	0.94 of revenue	$324,466	$2,366,905	-94.1	-69.4

Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

NPV1 = Project value without flexibility assuming PBI takes the innovation all the way to market launch.

NPV2 = Project value without flexibility when investment in basic R&D is assumed to be sunk and a collaborating takes the innovation from the applied R&D stage all the way to market launch.

ROV1 = Project value with flexibility assuming PBI takes the innovation all the way to market launch.

ROV2 = Project value with flexibility when investment in basic R&D is assumed to be sunk and a collaborating takes the innovation from the applied R&D stage all the way to market launch.

Table C.2 Results of the Sensitivity of ROV to Different Exercise Patterns

Scenario 1 (Basic R&D)	ROV1*	% change ROV1
a	$4,664,588	
e	$2,800,481	- 40%
Scenario 2 (Applied R&D)	**ROV2***	**% change in ROV2**
a	$18,486,957	
e	$17,311,434	- 6%

Note: Invest in the next R&D stage if ROV1* > $0; ROV2* > $0 otherwise abandon.
ROV1* and ROV2* in this table refers to the value of managerial flexibility estimated at time period t=0.

Scenario a = PBI is assumed to exercise its call option on the next stage or make abandonment decision at the beginning of each year with the information acquired from the completion of the previous year's investment. The overall R&D timeline of the project consist of a series of thirteen (13) call options.

Scenario e = PBI is assumed to exercise its call option on the next stage or make abandonment decision at the beginning of each stage with the information acquired from the completion of the previous stage's investment. The overall R&D timeline of the project consist of a series of five (5) call options

Table C.3 Results of the Sensitivity of NPV and ROV to More Time Steps

	Scenario 1 (Basic R&D)			Scenario 2 (Applied R&D)		
	NPV1	**ROV1**	**% change ROV1**	**NPV2**	**ROV2**	**% change ROV2**
Scenario a (Value of flexibility)	-$725,692	$4,664,588		$15,899,395	$18,486,957	
Scenario e (Value of flexibility)	-$751,954	$2,800,481	-40	$15,944,448	$17,311,433	-6

Note: Values that are bold refers to the base case values
Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Table C.4 Results of the Sensitivity of NPV and ROV to Changes in the Probability of Success Associated with the Basic R&D Stage

	Scenario 1 (Basic R&D)			
Basic R&D Probability of Success (%)	**NPV1 (million)**	**ROV1 (million)**	**% change NPV1**	**% change ROV1**
5	-$5.93	$0.53	-717.12	-90.14
10	-$4.89	$1.45	-573.70	-73.10
15	-$3.85	$2.42	-430.27	-55.28
20	-$2.81	$3.40	-286.85	-37.07
25	-$1.77	$4.40	-143.42	-18.62
30	**-$0.73**	**$5.41**	**0.00**	**0.00**
33	$0.00	$6.11	100.00	13.06
35	$0.32	$6.42	143.42	18.75
40	$1.36	$7.44	286.85	37.60
45	$2.40	$8.46	430.27	56.52
50	$3.44	$9.49	573.70	75.52
55	$4.48	$10.52	717.12	94.58
60	$5.52	$11.55	860.54	113.68
65	$6.56	$12.59	1,003.97	132.83
70	$7.60	$13.63	1,147.39	152.01
75	$8.64	$14.67	1,290.82	171.23

Note: Values that are bold refers to the base case values
Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Table C.5 Results of the Sensitivity of NPV and ROV to Changes in the Probability of Success Associated with the Applied R&D Stage

	Scenario 1 (Basic R&D)				Scenario 2 (Applied R&D)			
Applied R&D Probability of Success (%)	**NPV1 (million)**	**ROV1 (million)**	**% change NPV1**	**% change ROV1**	**NPV2 (million)**	**ROV2 (million)**	**% change NPV2**	**% change ROV2**
25	-$4.37	$1.41	-501.98	-73.85	$3.79	$7.63	-76.2	-59.8
30	-$3.85	$1.98	-430.27	-63.35	$5.52	$9.24	-65.3	-51.3
35	-$3.33	$2.55	-358.56	-52.83	$7.25	$10.86	-54.4	-42.8
40	-$2.81	$3.12	-286.85	-42.29	$8.98	$12.48	-43.5	-34.3
45	-$2.29	$3.69	-215.14	-31.73	$10.71	$14.10	-32.7	-25.7
50	-$1.77	$4.26	-143.42	-21.16	$12.44	$15.73	-21.8	-17.2
55	-$1.25	$4.84	-71.71	-10.59	$14.17	$17.36	-10.9	-8.6
60	**-$0.73**	**$5.41**	**0.00**	**0.00**	**$15.90**	**$18.99**	**0.0**	**0.0**
65	-$0.21	$5.98	71.71	10.59	$17.63	$20.62	10.9	8.6
67	$0.00	$6.21	100.00	14.77	$18.31	$21.26	15.2	12.0
70	$0.32	$6.55	143.42	21.19	$19.36	$22.25	21.8	17.2
75	$0.84	$7.13	215.14	31.80	$21.09	$23.88	32.7	25.8
80	$1.36	$7.70	286.85	42.41	$22.82	$25.52	43.5	34.4
85	$1.88	$8.28	358.56	53.03	$24.55	$27.15	54.4	43.0

Note: Values that are bold refers to the base case values
Sales volume in metric tonne = 225,000. Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Table C.6 Results of the Sensitivity of NPV and ROV to Changes in the Probability of Success Associated with the Prototype Stage

	Scenario 1 (Basic R&D)				Scenario 2 (Applied R&D)			
Prototype Stage Probability of Success (%)	**NPV1 (million)**	**ROV1 (million)**	**% change NPV1**	**% change ROV1**	**NPV2 (million)**	**ROV2 (million)**	**% change NPV2**	**% change ROV2**
35	-$4.06	$1.62	-458.96	-70.05	$4.82	$8.09	-69.7	-57.4
40	-$3.64	$2.09	-401.59	-61.30	$6.21	$9.45	-61.0	-50.2
45	-$3.22	$2.57	-344.22	-52.55	$7.59	$10.81	-52.2	-43.1
50	-$2.81	$3.04	-286.85	-43.80	$8.98	$12.17	-43.5	-35.9
55	-$2.39	$3.51	-229.48	-35.04	$10.36	$13.54	-34.8	-28.7
60	-$1.97	$3.99	-172.11	-26.28	$11.75	$14.90	-26.1	-21.5
65	-$1.56	$4.46	-114.74	-17.52	$13.13	$16.26	-17.4	-14.4
70	-$1.14	$4.93	-57.37	-8.76	$14.51	$17.62	-8.7	-7.2
75	**-$0.73**	**$5.41**	**0.00**	**0.00**	**$15.90**	**$18.99**	**0.0**	**0.0**
80	-$0.31	$5.88	57.37	8.76	$17.28	$20.35	8.7	7.2
84	$0.00	$6.23	100.00	15.28	$18.31	$21.36	15.2	12.5
85	$0.11	$6.36	114.74	17.53	$18.67	$21.71	17.4	14.4
90	$0.52	$6.83	172.11	26.30	$20.05	$23.08	26.1	21.5
95	$0.94	$7.30	229.48	35.06	$21.44	$24.44	34.8	28.7

Note: Values that are bold refers to the base case values
Sales volume in metric tonne = 225,000 Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Table C.7 Results of the Sensitivity of NPV and ROV to Changes in the Probability of Success Associated with the Scale-up Stage

	Scenario 1 (Basic R&D)				Scenario 2 (Applied R&D)			
Scale-up Stage Probability of Success (%)	**NPV1 (million)**	**ROV1 (million)**	**% change NPV1**	**% change ROV1**	**NPV2 (million)**	**ROV2 (million)**	**% change NPV2**	**% change ROV2**
40	-$4.03	$1.59	-455.58	-70.61	$4.91	$7.97	-69.1	-58.0
45	-$3.66	$2.01	-404.96	-62.77	$6.13	$9.19	-61.5	-51.6
50	-$3.30	$2.44	-354.34	-54.93	$7.35	$10.42	-53.8	-45.1
55	-$2.93	$2.86	-303.72	-47.08	$8.57	$11.64	-46.1	-38.7
60	-$2.56	$3.29	-253.10	-39.24	$9.79	$12.86	-38.4	-32.2
65	-$2.20	$3.71	-202.48	-31.39	$11.01	$14.09	-30.7	-25.8
70	-$1.83	$4.13	-151.86	-23.55	$12.23	$15.31	-23.0	-19.4
75	-$1.46	$4.56	-101.24	-15.70	$13.46	$16.54	-15.4	-12.9
80	-$1.09	$4.98	-50.62	-7.85	$14.68	$17.76	-7.7	-6.5
85	**-$0.73**	**$5.41**	**0.00**	**0.00**	**$15.90**	**$18.99**	**0.0**	**0.0**
90	-$0.36	$5.83	50.62	7.85	$17.12	$20.21	7.7	6.5
94.9	$0.00	$6.25	100.00	15.51	$18.31	$21.41	15.2	12.7
95	$0.01	$6.26	101.24	15.70	$18.34	$21.44	15.4	12.9
100	$0.38	$6.68	151.86	23.55	$19.56	$22.66	23.0	19.4

Note: Values that are bold refers to the base case values
Sales volume in metric tonne = 225,000 Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160

Table C.8 Results of the Sensitivity of NPV and ROV to a Decrease in All Technological Probabilities of Success using Increments of 2%

	Scenario 1 (Basic R&D)				Scenario 2 (Applied R&D)			
Technological Probabilities of Success	**NPV1 (million)**	**ROV1 (million)**	**% change NPV1**	**% change ROV1**	**NPV2 (million)**	**ROV2 (million)**	**% change NPV2**	**% change ROV2**
0%	-$0.73	$5.41	0.00	0.00	$15.90	$18.99	0.00	0.00
-2%	-$1.62	$4.47	-122.63	-17.34	$14.21	$17.35	-10.61	-8.64
-4%	-$2.41	$3.64	-232.59	-32.73	$12.62	$15.80	-20.64	-16.79
-6%	-$3.13	$2.90	-330.76	-46.30	$11.11	$14.34	-30.10	-24.46
-8%	-$3.76	$2.26	-417.94	-58.17	$9.70	$12.97	-39.01	-31.67
-10%	-$4.32	$1.70	-494.95	-68.47	$8.37	$11.69	-47.38	-38.44
-12%	-$4.81	$1.23	-562.56	-77.31	$7.12	$10.49	-55.23	-44.77
-14%	-$5.24	$0.82	-621.50	-84.80	$5.95	$9.36	-62.58	-50.68
-15%	-$5.43	$0.65	-647.94	-88.07	$5.39	$8.83	-66.07	-53.48
-16%	-$5.61	$0.49	-672.48	-91.03	$4.86	$8.32	-69.45	-56.18
-18%	-$5.92	$0.21	-716.20	-96.10	$3.84	$7.35	-75.84	-61.29
-20%	-$6.19	$0.03	-753.30	-99.41	$2.90	$6.45	-81.78	-66.02
-22%	-$6.42	$0.00	-784.42	-100.00	$2.02	$5.62	-87.29	-70.38

% Reduction in all Prob.	**0%**	**-2%**	**-4%**	**-6%**	**-8%**	**-10%**	**-12%**	**-14%**	**-16%**	**-18%**	**-20%**	**-22%**
Basic R&D	0.30	0.28	0.26	0.24	0.22	0.20	0.18	0.16	0.14	0.12	0.10	0.08
Applied R&D	0.60	0.58	0.56	0.54	0.52	0.50	0.48	0.46	0.44	0.42	0.40	0.38
Prototype	0.75	0.73	0.71	0.69	0.67	0.65	0.63	0.61	0.59	0.57	0.55	0.53
Scale-up	0.85	0.83	0.81	0.79	0.77	0.75	0.73	0.71	0.69	0.67	0.65	0.63

Sales volume in metric tonne = 225,000 Price per metric tonne of reduced ANF canola meal = $208

Table C.9 Results of the Sensitivity of NPV and ROV to Changes in Price Volatility

	Scenario 1 (Basic R&D)				Scenario 2 (Applied R&D)			
Price Volatility (%)	**NPV1 (million)**	**ROV1 (million)**	**% change NPV1**	**% change ROV1**	**NPV2 (million)**	**ROV2 (million)**	**% change NPV2**	**% change ROV2**
1	-$0.73	$5.41	0.00	0.00	$15.90	$18.99	0.0	0.0
7	-$0.73	$5.41	0.00	0.00	$15.90	$18.99	0.0	0.0
8	-$0.73	$5.41	0.00	0.00	$15.90	$18.99	0.0	0.0
9	**-$0.73**	**$5.41**	**0.00**	**0.00**	**$15.90**	**$18.99**	**0.0**	**0.0**
10	-$0.73	$5.41	0.00	0.00	$15.90	$18.99	0.0	0.0
20	-$0.73	$5.41	0.00	0.00	$15.90	$18.99	0.0	0.0
30	-$0.73	$5.41	0.00	0.00	$15.90	$18.99	0.0	0.0
40	-$0.73	$5.41	0.00	0.06	$15.90	$18.99	0.0	0.0
50	-$0.73	$5.43	0.00	0.42	$15.90	$18.99	0.0	0.0
60	-$0.73	$5.47	0.00	1.25	$15.90	$19.02	0.0	0.2
70	-$0.73	$5.54	0.00	2.45	$15.90	$19.09	0.0	0.5
80	-$0.73	$5.63	0.00	4.13	$15.90	$19.17	0.0	1.0
90	-$0.73	$5.73	0.00	6.04	$15.90	$19.31	0.0	1.7
100	-$0.73	$5.83	0.00	7.77	$15.90	$19.44	0.0	2.4
150	-$0.73	$6.31	0.00	16.62	$15.90	$20.08	0.0	5.8

Note: Values that are bold refers to the base case values
Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Table C.10 Results of the Sensitivity of NPV and ROV to Changes in the Risk-Free Rate

	Scenario 1 (Basic R&D)				Scenario 2 (Applied R&D)			
Risk-free Rate (%)	**NPV1 (million)**	**ROV1 (million)**	**% change NPV1**	**% change ROV1**	**NPV2 (million)**	**ROV2 (million)**	**% change NPV2**	**% change ROV2**
1.0	-$2.09	$4.32	-187.72	-20.11	$15.06	$18.09	-5.3	-4.7
1.5	-$1.79	$4.53	-146.82	-16.26	$15.23	$18.26	-4.2	-3.8
2.0	-$1.51	$4.74	-107.72	-12.33	$15.40	$18.44	-3.2	-2.9
2.5	-$1.24	$4.96	-70.29	-8.32	$15.57	$18.62	-2.1	-1.9
3.0	-$0.98	$5.18	-34.42	-4.21	$15.73	$18.80	-1.0	-1.0
3.5	**-$0.73**	**$5.41**	**0.00**	**0.00**	**$15.90**	**$18.99**	**0.0**	**0.0**
4.0	-$0.49	$5.64	33.07	4.31	$16.06	$19.18	1.0	1.0
4.5	-$0.25	$5.88	64.89	8.72	$16.23	$19.37	2.1	2.0
5.0	-$0.03	$6.12	95.55	13.25	$16.39	$19.56	3.1	3.0
5.1	$0.00	$6.16	100.00	13.93	$16.42	$19.59	3.3	3.2
5.5	$0.18	$6.38	125.12	17.89	$16.56	$19.76	4.1	4.1
6.0	$0.39	$6.63	153.70	22.66	$16.72	$19.97	5.2	5.2
6.5	$0.59	$6.90	181.34	27.56	$16.88	$20.18	6.2	6.3

Note: Values that are bold refers to the base case values
Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Table C.11 Results of the Sensitivity of NPV and ROV to Changes in the Discount Rate

	Scenario 1 (Basic R&D)				Scenario 2 (Applied R&D)			
Discount Rate (%)	**NPV1 (million)**	**ROV1 (million)**	**% change NPV1**	**% change ROV1**	**NPV2 (million)**	**ROV2 (million)**	**% change NPV2**	**% change ROV2**
5	$18.01	$27.66	2,581.63	411.48	$78.20	$83.47	391.8	339.6
10	$5.52	$12.82	860.54	137.16	$36.67	$40.48	130.6	113.2
15	$1.36	$7.88	286.85	45.72	$22.82	$26.15	43.5	37.7
18	$0.00	$6.27	100.00	15.94	$18.31	$21.48	15.2	13.2
20	**-$0.73**	**$5.41**	**0.00**	**0.00**	**$15.90**	**$18.99**	**0.0**	**0.0**
25	-$1.97	$3.92	-172.11	-27.43	$11.75	$14.69	-26.1	-22.6
30	-$2.81	$2.94	-286.85	-45.72	$8.98	$11.82	-43.5	-37.7
35	-$3.40	$2.23	-368.80	-58.78	$7.00	$9.78	-56.0	-48.5
40	-$3.85	$1.70	-430.27	-68.58	$5.52	$8.24	-65.3	-56.6
45	-$4.20	$1.29	-478.08	-76.20	$4.36	$7.05	-72.6	-62.9
50	-$4.47	$0.96	-516.33	-82.30	$3.44	$6.09	-78.4	-67.9

Note: Values that are bold refers to the base case values
Sales volume in metric tonne = 225,000. Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Table C.12 Results of the Sensitivity of NPV and ROV to Changes in the Sales Volume of Reduced ANF Canola Meal

	Scenario 1 (Basic R&D)				Scenario 2 (Applied R&D)			
Yearly sales volume (tonnes)	**NPV1 (million)**	**ROV1 (million)**	**% change NPV1**	**% change ROV1**	**NPV2 (million)**	**ROV2 (million)**	**% change NPV2**	**% change ROV2**
225,000	**-$0.73**	**$5.41**	**0.0**	**0.0**	**$15.90**	**$18.99**	**0.0**	**0.0**
251,146	$0.00	$6.27	100.0	15.9	$18.31	$21.48	15.2	13.2
450,000	$5.52	$12.82	860.5	137.2	$36.67	$40.48	130.6	113.2
675,000	$11.76	$20.24	1,721.1	274.3	$57.43	$61.97	261.2	226.4
900,000	$18.01	$27.66	2,581.6	411.5	$78.20	$83.47	391.8	339.6
1,125,000	$24.25	$35.08	3,442.2	548.6	$98.97	$104.96	522.4	452.8
1,350,000	$30.50	$42.49	4,302.7	685.8	$119.73	$126.45	653.1	566.0
1,575,000	$36.74	$49.91	5,163.3	823.0	$140.50	$147.95	783.7	679.2
1,800,000	$42.99	$57.33	6,023.8	960.1	$161.27	$169.44	914.3	792.4
2,025,000	$49.23	$64.74	6,884.4	1,097.3	$182.03	$190.93	1,044.9	905.6
2,250,000	$55.48	$72.16	7,744.9	1,234.4	$202.80	$212.43	1,175.5	1,018.8
2,475,000	$61.72	$79.58	8,605.4	1,371.6	$223.57	$233.92	1,306.1	1,132.0
2,700,000	$67.97	$86.99	9,466.0	1,508.7	$244.33	$255.41	1,436.7	1,245.2
2,925,000	$74.21	$94.41	10,326.5	1,645.9	$265.10	$276.91	1,567.3	1,358.4
3,150,000	$80.46	$101.83	11,187.1	1,783.1	$285.86	$298.40	1,698.0	1,471.6
3,375,000	$86.70	$109.25	12,047.6	1,920.2	$306.63	$319.89	1,828.6	1,584.8
3,600,000	$92.95	$116.66	12,908.2	2,057.4	$327.40	$341.39	1,959.2	1,698.0
3,825,000	$99.19	$124.08	13,768.7	2,194.5	$348.16	$362.88	2,089.8	1,811.2
3,990,310	$103.78	$129.53	14,401.0	2,295.3	$363.42	$378.67	2,185.8	1,894.4

Note: Values that are bold refers to the base case values
Sales volume in metric tonne = 225,000. Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Table C.13 Results of the Sensitivity of NPV and ROV to Changes in the Price of Reduced ANF Canola Meal (Firm Level Break-even Price)

	Scenario 1 (Basic R&D)				Scenario 2 (Applied R&D)			
Price	NPV1 (million)	ROV1 (million)	% change NPV1	% change ROV1	NPV2 (million)	ROV2 (million)	% change NPV2	% change ROV2
208.0	**-$0.73**	**$5.41**	**0.00**	**0.00**	**$15.90**	**$18.99**	**0.0**	**0.0**
203.2	-$1.35	$4.67	-86.05	-13.72	$13.82	$16.84	-13.1	-11.3
198.4	-$1.97	$3.92	-172.11	-27.43	$11.75	$14.69	-26.1	-22.6
193.6	-$2.60	$3.18	-258.16	-41.15	$9.67	$12.54	-39.2	-34.0
188.8	-$3.22	$2.44	-344.22	-54.86	$7.59	$10.39	-52.2	-45.3
184.0	-$3.85	$1.70	-430.27	-68.58	$5.52	$8.24	-65.3	-56.6
179.2	-$4.47	$0.96	-516.33	-82.30	$3.44	$6.09	-78.4	-67.9
177.8	-$4.65	$0.74	-541.20	-86.26	$2.84	$5.47	-82.1	-71.2
174.4	-$5.10	$0.23	-602.38	-95.74	$1.36	$3.94	-91.4	-79.2
169.6	-$5.72	$0.00	-688.44	-100.00	-$0.71	$1.79	-104.5	-90.6
164.8	-$6.35	$0.00	-774.49	-100.00	-$2.79	$0.00	-117.6	-100.0
160.0	-$6.97	$0.00	-860.54	-100.00	-$4.87	$0.00	-130.6	-100.0

Note: Values that are bold refers to the base case values
Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Table C.14 Results of the Sensitivity of NPV and ROV to Changes in the Price of Reduced ANF Canola Meal (Industry Level Break-even Price)

	Scenario 1 (Basic R&D)				Scenario 2 (Applied R&D)			
Price	NPV1 (million)	ROV1 (million)	% change NPV1	% change ROV1	NPV2 (million)	ROV2 (million)	% change NPV2	% change ROV2
$208.00	**$103.78**	**$129.53**	**0.00**	**0.00**	**$363.42**	**$378.67**	**0.00**	**0.00**
$203.20	$92.71	$116.37	-10.67	-10.16	$326.59	$340.55	-10.13	-10.07
$198.40	$81.63	$103.22	-21.34	-20.31	$289.76	$302.44	-20.27	-20.13
$193.60	$70.56	$90.07	-32.01	-30.47	$252.94	$264.32	-30.40	-30.20
$188.80	$59.48	$76.91	-42.69	-40.62	$216.11	$226.20	-40.54	-40.26
$184.00	$48.41	$63.76	-53.36	-50.78	$179.28	$188.08	-50.67	-50.33
$179.20	$37.33	$50.61	-64.03	-60.93	$142.45	$149.97	-60.80	-60.40
$174.40	$26.25	$37.45	-74.70	-71.09	$105.62	$111.85	-70.94	-70.46
$169.60	$15.18	$24.30	-85.37	-81.24	$68.79	$73.73	-81.07	-80.53
$164.80	$4.10	$11.14	-96.04	-91.40	$31.96	$35.61	-91.21	-90.60
$163.02	$0.00	$6.27	-100.00	-95.16	$18.31	$21.48	-94.96	-94.33
$161.01	-$4.64	$0.76	-104.47	-99.41	$2.88	$5.51	-99.21	-98.54
$161.00	-$4.66	$0.73	-104.49	-99.44	$2.81	$5.43	-99.23	-98.56
$160.00	-$6.97	$0.00	-106.72	-100.00	-$4.87	$0.00	-101.34	-100.00

Note: Values that are bold refers to the base case values
Sales volume in metric tonne = 3,990,310
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Table C.15 Results of the Sensitivity of NPV and ROV to Changes in Basic R&D Cost

	Scenario 1 (Basic R&D)			
Basic R&D Cost	**NPV1 (million)**	**ROV1 (million)**	**% change NPV1**	**% change ROV1**
$371,505	$0.64	$6.37	1.88	17.81
$445,806	$0.37	$6.18	1.50	14.25
$520,107	$0.09	$5.99	1.13	10.68
$545,439	$0.00	$5.92	1.00	9.47
$594,408	-$0.18	$5.79	0.75	7.12
$668,709	-$0.45	$5.60	0.38	3.56
$743,010	**-$0.73**	**$5.41**	**0.00**	**0.00**
$817,311	-$1.00	$5.22	-0.38	-3.56
$891,612	-$1.27	$5.02	-0.75	-7.12
$965,913	-$1.54	$4.83	-1.13	-10.68
$1,040,214	-$1.82	$4.64	-1.50	-14.25
$1,114,515	-$2.09	$4.44	-1.88	-17.81

Note: Values that are bold refers to the base case values
Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Table C.16 Results of the Sensitivity of NPV and ROV to Changes in Applied R&D Cost

	Scenario 1 (Basic R&D)				Scenario 2 (Applied R&D)			
Applied R&D Cost	**NPV1 (million)**	**ROV1 (million)**	**% change NPV1**	**% change ROV1**	**NPV2 (million)**	**ROV2 (million)**	**% change NPV2**	**% change ROV2**
100,000	$0.55	$5.74	1.76	6.17	$17.37	$20.26	0.09	0.07
150,000	$0.39	$5.70	1.54	5.39	$17.18	$20.10	0.08	0.06
200,000	$0.23	$5.66	1.32	4.62	$17.00	$19.94	0.07	0.05
250,000	$0.07	$5.62	1.10	3.85	$16.82	$19.78	0.06	0.04
300,000	-$0.09	$5.57	0.88	3.08	$16.63	$19.62	0.05	0.03
350,000	-$0.25	$5.53	0.66	2.31	$16.45	$19.47	0.03	0.03
400,000	-$0.41	$5.49	0.44	1.54	$16.27	$19.31	0.02	0.02
450,000	-$0.57	$5.45	0.22	0.77	$16.08	$19.15	0.01	0.01
500,000	**-$0.73**	**$5.41**	**0.00**	**0.00**	**$15.90**	**$18.99**	**0.00**	**0.00**
550,000	-$0.89	$5.37	-0.22	-0.77	$15.72	$18.83	-0.01	-0.01
600,000	-$1.05	$5.32	-0.44	-1.54	$15.53	$18.67	-0.02	-0.02

Note: Values that are bold refers to the base case values
Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Table C.17 Results of the Sensitivity of NPV and ROV to Changes in Prototype Cost

	Scenario 1 (Basic R&D)				Scenario 2 (Applied R&D)			
Prototype Cost	**NPV1 (million)**	**ROV1 (million)**	**% change NPV1**	**% change ROV1**	**NPV2 (million)**	**ROV2 (million)**	**% change NPV2**	**% change ROV2**
$250,000	-$0.37	$5.47	0.50	1.22	$16.31	$19.23	0.03	0.01
$300,000	-$0.44	$5.46	0.40	0.98	$16.23	$19.18	0.02	0.01
$350,000	-$0.51	$5.45	0.30	0.73	$16.15	$19.13	0.02	0.01
$400,000	-$0.58	$5.43	0.20	0.49	$16.06	$19.08	0.01	0.01
$450,000	-$0.65	$5.42	0.10	0.24	$15.98	$19.03	0.01	0.00
$500,000	**-$0.73**	**$5.41**	**0.00**	**0.00**	**$15.90**	**$18.99**	**0.00**	**0.00**
$550,000	-$0.80	$5.39	-0.10	-0.24	$15.82	$18.94	-0.01	0.00
$600,000	-$0.87	$5.38	-0.20	-0.49	$15.73	$18.89	-0.01	-0.01
$650,000	-$0.94	$5.37	-0.30	-0.73	$15.65	$18.84	-0.02	-0.01
$700,000	-$1.01	$5.35	-0.40	-0.98	$15.57	$18.79	-0.02	-0.01
$750,000	-$1.09	$5.34	-0.50	-1.22	$15.49	$18.75	-0.03	-0.01

Note: Values that are bold refers to the base case values
Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Table C.18 Results of the Sensitivity of NPV and ROV to Changes in Scale-up Cost

	Scenario 1 (Basic R&D)				Scenario 2 (Applied R&D)			
Scale-up Cost	**NPV1 (million)**	**ROV1 (million)**	**% change NPV1**	**% change ROV1**	**NPV2 (million)**	**ROV2 (million)**	**% change NPV2**	**% change ROV2**
$250,000	-$0.39	$5.46	0.46	0.94	$16.29	$19.16	0.02	0.01
$300,000	-$0.46	$5.45	0.37	0.75	$16.21	$19.13	0.02	0.01
$350,000	-$0.52	$5.44	0.28	0.57	$16.13	$19.09	0.01	0.01
$400,000	-$0.59	$5.43	0.19	0.38	$16.05	$19.06	0.01	0.00
$450,000	-$0.66	$5.42	0.09	0.19	$15.98	$19.02	0.00	0.00
$500,000	**-$0.73**	**$5.41**	**0.00**	**0.00**	**$15.90**	**$18.99**	**0.00**	**0.00**
$550,000	-$0.79	$5.40	-0.09	-0.19	$15.82	$18.95	0.00	0.00
$600,000	-$0.86	$5.39	-0.19	-0.38	$15.74	$18.92	-0.01	0.00
$650,000	-$0.93	$5.38	-0.28	-0.57	$15.67	$18.88	-0.01	-0.01
$700,000	-$1.00	$5.37	-0.37	-0.75	$15.59	$18.85	-0.02	-0.01
$750,000	-$1.06	$5.36	-0.46	-0.94	$15.51	$18.81	-0.02	-0.01

Note: Values that are bold refers to the base case values
Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.

Table C.19 Results of the Sensitivity of NPV and ROV to Changes in Commercialization Cost

	Scenario 1 (Basic R&D)				Scenario 2 (Applied R&D)			
Commercialization cost	**NPV1 (million)**	**ROV1 (million)**	**% change NPV1**	**% change ROV1**	**NPV2 (million)**	**ROV2 (million)**	**% change NPV2**	**% change ROV2**
$974,608	-$0.10	$5.50	0.86	1.63	$16.61	$19.28	0.04	0.02
$1,169,529	-$0.23	$5.48	0.69	1.30	$16.47	$19.22	0.04	0.01
$1,364,451	-$0.35	$5.46	0.52	0.98	$16.33	$19.16	0.03	0.01
$1,559,372	-$0.48	$5.44	0.34	0.65	$16.19	$19.10	0.02	0.01
$1,754,294	-$0.60	$5.43	0.17	0.33	$16.04	$19.05	0.01	0.00
$1,949,215	**-$0.73**	**$5.41**	**0.00**	**0.00**	**$15.90**	**$18.99**	**0.00**	**0.00**
$2,144,137	-$0.85	$5.39	-0.17	-0.33	$15.76	$18.93	-0.01	0.00
$2,339,058	-$0.97	$5.37	-0.34	-0.65	$15.61	$18.87	-0.02	-0.01
$2,533,980	-$1.10	$5.35	-0.52	-0.98	$15.47	$18.81	-0.03	-0.01
$2,728,901	-$1.22	$5.34	-0.69	-1.30	$15.33	$18.75	-0.04	-0.01
$2,923,823	-$1.35	$5.32	-0.86	-1.63	$15.18	$18.69	-0.04	-0.02

Note: Values that are bold refers to the base case values
Sales volume in metric tonne = 225,000
Price per metric tonne of reduced ANF canola meal = $208
Price per metric tonne of conventional (unreduced) canola meal = $160
Invest in the next R&D stage if ROV1 > $743,010; ROV2 > $500,000 otherwise abandon.