Valuing Investments in Technology under Uncertainty:

A Real Options Approach.

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Utkarsh N. Khamesra

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Advisers: Dr. Richard Lindeke

Dr. Hongyi Chen

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Abstract

This thesis highlights the importance of real options valuation for evaluating the true value of projects that are subject to uncertainty in the future. This is in contrast to the traditional evaluation strategies, such as discounted cash flow analysis, internal rate of return analysis, cost benefit analysis, Monte Carlo simulation based probabilistic models, scenario based analyses etc., that have been used in the past to value projects that are drawn years in advance. These traditional methods were many times ineffective in capturing the complete risk and the flexibility of the decision making process. The true value of technology investments that are subject to future uncertainty can only be evaluated effectively by incorporating decision flexibility during valuation.

The research throws light on the recent developments in the Real Options analysis field and compares and contrasts different methods, techniques and insights that have been proposed by leading researchers in the field. The thesis aims at ways by which engineering managers can effectively evaluate project risks and gained value using a real options approach.

The real option method is demonstrated using a case study on the acquisition of Numonyx by Micron Technology Inc. (NASDAQ:MU) in May 2010. Under assumptions it has been shown that by incorporating managerial flexibility in the valuation provides a better estimate compared to traditional discounted cash flow techniques.

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1.0 Introduction

Whenever there are investments to be made or projects to be started, they are always preceded by risk analysis and value analysis. Thus when a report is submitted for a new project proposal or an investment, Project Managers are expected to evaluate in detail how the new investment is aligned with the mission and vision of the organization. Beyond these criteria one of the most important considerations is what value would that investment adds to the company? Will the investment be able to generate sufficient value to justify the investment into it in the first place?

The dilemma faced by most of the technology managers in today's world is to evaluate ahead of time whether a particular technological investment would be worthwhile or not. Unfortunately for the managers they are bounded by ever tightening timelines available for making these types of critical decisions. Issues with evaluating correct project value is further doubled when the technology under the question is subject to uncertainty.

Decision making requires the decision executor to have complete knowledge of all the possible courses of actions and all the possibilities of occurrences these outcomes. This knowledge stream is dependent on the decision maker's experience and knowledge of the processes that are involved. It also depends in large part on the computing ability of the decision maker to select the optimal course of action in today's rapidly changing and competitive environment.

One of the greatest challenges facing an engineering manager is judging uncertainties, and their potential to determine a priori alternate courses of action if these potential uncertainties turn into realities. A large and growing body of behavioral research shows that humans (and especially engineering decision makers) are not particularly good at decision making in the face of uncertainty [1].

Any strategic investment proves to be a challenging and a risky decision for a firm as it can offer huge rewards to the firm but could also end up causing great losses. The major difficulty a firm faces is justifying and evaluating such type of decisions using what are often considered the normal executive skills and investment strategies.

Managers facing the evaluation problems of an Information Technology (IT) investment have used various methods from simple computational formulae to very complex techniques that weave both quantitative and qualitative analyses together. Among them, quantitative methods are common in evaluating new technology, but these types of methods that are often used in capital investment analysis do not necessarily capture the entire impact of new technology adoption [2].The reason is that such investments have intangible benefit characteristics such as enhancement capabilities, long term competitive advantages etc., as well as intangible sunk costs if the new technology cannot be effectively adopted.

Real options (RO) can be defined as an alternative or a choice that becomes available with a business investment opportunity. These alternatives or choices are usually tangible assets and hence the name real options. According to Busby and Pitts [3], Real Options frequently occur in the managerial decision-making process and managers must recognize the importance of securing flexibility in capital investments. However, most managers still use the traditional formalized methods, such as Net present value (NPV) and Return on Investment (ROI), because they are skeptical of new analytical tools and they have difficulty in abandoning ongoing investments.

In this thesis the author presents the shortcomings of traditional valuation methods, advantages of using real options, different real option application techniques, short comings of real options valuation and finally the application of real option analysis using a case study of the acquisition of the Swedish memory maker Numonyx by American memory maker MU.

2.0 Literature Review

2.1 History of real options theory:

Options pricing theory emerged in the early 1900's, when Louis Bachelier published a thesis, "Théorie de la speculation" , which was separately (5 years later) developed by Einstein (particle motion physics) and Smoluchowski later, known to the world as the Brownian motion [4]. Brownian motion was a simple continuous stochastic process used to model fluctuations, or random behavior, of an asset price. But neither Bachelier nor Einstein were able to prove or justify the Brownian theory. This Brownian motion theory was later proved by Norbert Wiener in 1932 and hence many times the theory is called the Wiener process [5].

In the year 1960, significant research was performed by Paul A. Samuelson. Samuelson considered long term equity options and used the "Geometric Brownian" to model the random behavior of the underlying stock [6]. But one of the problems in Samuelson's proposal was that it offered no means for a buyer and a seller, having different risk aversions, to settle on a common price for an option. This problem was addressed in a completely new way by Black and Scholes in 1973, in their Noble Prize winning "Options Pricing Theory", which is also referred to as Black-Scholes theory/model or derivative pricing theory [7].

Black and Scholes formulated the options pricing formula, using a partial differentiation formula for valuing contingent claims on a traded underlier and applying different boundary conditions to European call options [8]. Cox, Ross and Rubinstein in their 1979 paper, used risk neutral valuations to develop the method of binomial trees. This is one of the predominant methodologies that are used for valuation in complete markets [9]

2.2 Defining Real Options

The term 'Real Option' was used for the first time by Stewart Myers [10]. Myers refers to it as the application of option pricing theory to the valuation of non-financial or "real" investments with learning and flexibility, such as multi-stage research and development (R&D) investments, modular manufacturing plant expansion and the like [10]. The application of option valuation techniques to capital budgeting problems implies that a real option is a right, but not an obligation, to undertake a financial decision or to make an investment. Myers, in his article, suggests that the value of a company arises from the assets that the company already has and also the potential opportunities to invest in or purchase real assets at a favorable price in the future. This later asset category he termed real options. Here Myers draws attention to the similarities between a real option and a financial option. Like a financial option, if a company explores the possibility of buying an asset (investment) it should be termed a "call option". If a company wants to defer or divest assets in the future when prices are (more) favorable, it can be called a "put option". The major difference between financial options and real options basically can be distilled down this way: financial options have fixed prices and fixed expiry dates, whereas for real options, the exercise prices and expiration time are generally functions of the specific resources involved and market situations or business capabilities depending on the type of option under consideration.

The author must first define what an option is before its definition as a real options and financial options makes sense.

An option is defined as, "the right but not the obligation to take an action (at a cost, called the exercise price) for a predetermined period of time (called the maturity of the option)." Then "a financial option is contingent on the uncertain value of a financial security." while "A real option is contingent on the uncertain value of a real asset."

Next, analogies for real options as compared to traditional financial option pricing methods will be made.

Call option analogy: In an irreversible investment strategy, just like a financial call option, the engineering manager has the right to exercise the option of buying an asset but is not obligated until the time the option expires (maturity of the option).

Dividend yield analogy: The net cash flows generated by the asset can be viewed as analogous to a dividend from a stock or the periodic revenue from the asset in general.

As McGrath, et al. have identified in [11], most views about real options have in common is the idea of a limited commitment that enables future decision rights. They identify four different but often similar concepts in the real options literature:

1. The idea of option value as a component of the total value of the firm, where it represents the growth opportunities

   As identified by Miller and Modigliani [12], a firm's market value is comprised of two components, first is the present value of those cash flows that will be generated by the assets that are in place, and second is the present value of growth opportunities.

2. A specific investment proposal with option like properties

   Studies performed by Kester [13], and Kogut [14] describe option value as related to the preservation of choices, meaning that the firm can take actions like scaling up/down or abandoning changes when more information is available, rather than making a full commitment to a given path at the outset of a project, investment alternative, or initiative.

3. Choices that might pertain to one or more proposals

   Trigeorgis [15], has identified the following as real options:

- The option to defer an investment or decision until the decision maker can see that the outcome justifies the investment.
- The option to stage and sequence investment wherein the decision maker invests in stages and each stage can be viewed as an option on the value of subsequent stages.
- The option to abandon where the decision maker abandons the investments midway due to negative market conditions and salvages by selling of assets and investments made in the project.
- The option to grow (growth option), where the decision maker tries to extend support by making further investments where an earlier investment, seems to be fruitful in the future due to favorable market conditions.
- Multiple interacting options, wherein multiple upside (potential enhancing) options (analogous to a call option) and down side (protection) options (put options) are interacting. Here the combined value of these options differs from their individual option values.

4. The use of options reasoning as a heuristic for strategy.

According to Bowman and Hurry [16], resources with option values generate choices and allow preferential access to future opportunities. They propose that decisions regarding individual options are actually best understood as a sequential "option chain" involving the recognition by managers that an option does exist and the investments are in a sequence where each investment draws its value from a subsequent investment opportunity.

At times an investment can be postponed or deferred until market conditions are favorable. Similarly, a project may be abandoned in order to cut losses if the market conditions become unfavorable. Sometimes the manager may have to shrink operations or extend more resources to an investment to cash in on prevailing opportunities. This flexibility of decision implies that the manager will have the ability and influence to limit the downside risk of loss, but retain relatively unlimited upside potential for gain in profit, market share, etc [17]. By making an initial investment with flexibility, the company reduces the cost of altering its strategy [17].

As compared to the traditional methods, the real options approach offers a better method for considering investment alternatives. It is often proven to be a favorable way to decide on expenditures of limited resources as they provide flexibility needed by the firm to invest, scale up, divest or decide on what resources to employ, only when such type of moves prove to be advantageous. Real options analysis can also use NPV type of cash flow analysis by projecting future cash flows after choosing an appropriate discount rate but, additionally, it offers the managers opportunities to intervene in ways that would add value over time.

Although Real Options tend to be focused on comparing expected returns of decisions, Dixit and Pindyck [18], suggest that firms should not invest in projects, only based on the opportunity cost of capital, but must also by consider factors like market capture, innovation, etc. Managers can make choices about the project's characteristics and this flexibility creates embedded options. These options add value to the project and invalidate the traditional discounted cash flow (DCF) based rules.

Real options have also been combined with Game theory in order to address the risks associated with competition in a particular environment [19]. In the game theory approach player one, being the decision makers' of a company and the other players, being the competitor company or the market as a whole, analyzes the business alternatives under the threat of competition [19].

Real options were developed in the financial sectors and have been modified for application in other sectors by various researchers. The question that arises here is that with traditional methods like discounted cash flow analysis and net present value methods already in use to justify investments, what additional benefits do real options offer the engineering manager in assessing future investments?

K.T. Yeo and Fasheng Qiu [20], explain that traditional techniques employing discounted cash flow analysis ignores the upside potentials to an investment when managerial flexibility and innovations take the focus. Corporate engineering managers have to make decisions in the present to provide for sustainable success in the future. These corporate engineering managers' decisions typically are regarding 'high-tech' research and development, entrance into new product markets, implementation of major enterprise information systems, business acquisitions or direct foreign investments in off-shore manufacturing facilities, etc. Thus when their companies are operating in a turbulent market environment, which is changing constantly in terms of trends and innovations, they need to have maximal flexibility in their decision making as offered by Real Options decision techniques.

The traditional methods generally assume that companies would follow a predetermined sequential planning path with predetermined cash flow stream, revenue in flows and out flows, interest rates...etc. But this assumption is far from the current business climate's reality. As Managers have to be constantly on the lookout for changes in the business environment, technological innovations, market trends, financial conditions etc, using the traditional methods of evaluation prevent them from valuing the flexibility involved in their complex decision paths.

Most evaluations of investments in new technologies use complex computational formulas to capture qualitative and quantitative impacts together. But these types of calculations do not necessarily capture the entire impact of new technology adoption [2]. The managers in IT areas face investment problems requiring the identification of risks involved as well as the payoffs involved with each decision. Missing complete information adds to the woes of the decision taker [21]. Kim and Sander [21], suggest that one of the problems in evaluating IT investments is that many performance metrics are flawed. It is mentioned that ROI, discounted cash flow, return on equity and/or assets are (usually) wrong as they are generally inflated and thus true profitability of the investments are not represented effectively. Timing of cash flows also can distort the evaluation of a project and its outcome. NPV methods account for short term improvements but not quality and efficiency improvements. So the main aim for companies is to decide what the performance should be under the given current conditions and what should be, and the target performance, for future strategies will be. Kim and Sander suggest that due to the previously mentioned concerns the only way that a manager can solve these dilemmas is by using the RO approach.

2.3 Various types of real options

Various types of real options as identified by Kim and Sander [21], Amram and Kulatilaka [22] and Benaroch [23], may be summarized into seven main types, as introduced below.

1. Growth options:

In growth options the company, if it sees an opportunity, might scale up, switch up or scope up (exploiting prior investment), to gain market share and advantage of entering as a new player. There might be an opportunity to invest in a loss making strategy that may make way for potentially valuable follow on investments.

An example of growth option would be of Google's free web based applications and services. Google started offering these services for free in order to gain market share of users using Google's services. Google does not gain directly from offering free services but rather used these free offerings for mining data on its user preferences which helps Google make its AdSense Network more effective in helping companies advertise the right products to the right kind of customers or people who would potentially buy their product.

2. Staging options:

Staging options are mostly used in scenarios dealing with long development capital intensive projects like pharmaceutical R&D and multistage oil exploration and production development. Here the outcome is uncertain and the companies retain the option to abandon/scale up or scale down the project at any time.

An example of staging option: Suppose a mega-multi regional manufacturing corporation wants to implement a new manufacturing process, but the benefits to be gained remain uncertain. The Corporation has the choice to invest money all at once at all of its manufacturing locations, or the company can stage the investment on a particular site, and only invest in other site after the new manufacturing process shows promise.

3. Deferment options:

There are times when the postponement of a project allows the decision maker to learn more about the potential project, product, or market outcomes before a decision is made. Defer options are usually used in order to learn from the first mover in a new market in order to understand more about an expected market response.

An example of defer option: An oil exploration and extraction company might buy the rights to explore and extract oil from certain oil fields. If the prices of oil are lower in the market than the extraction cost, the company may defer the option to extraction of oil, but the company can still hold on to the rights to extract oil if the company anticipates a future price rise which will make the option of extracting the oil profitable.

4. Exit or abandon option:

This option allows a manager of a project to abandon it if the market conditions worsen, in order to avoid further losses of running the operation.

An example of exit or abandon option: During the recent economic crisis, when GM had to abandon two of its brands “Saturn” and “Pontiac” to cut down its losses and insure its own survival [24].

5. Sourcing options:

Outsourcing and subcontracting can transfer risk of in-house failure or committing internal resources to risky production.

An example of sourcing option would be of the automobile battery supplier A/C Delco from whom automobile manufacturers like Ford and General Motors (G.M.) purchase automobile batteries. To Ford or GM, the option is whether to invest their time and resources to make batteries in-house or outsource them. But since making batteries is not their production focus, it has proven to be better to outsource battery production to a competent company like A/C Delco, even if in house manufacturing costs would be lower. Thus outsourcing frees up capital for Ford and GM to invest in other technology areas where they may see more return or better returns.

6. Business scope options:

A business operation can be scaled up or shrunk according to the market conditions. This scope option provides a high level of flexibility, which may prove to be highly rewarding.

A business scope example: Amazon in the year 2000 acquired a 5% stake in a company called Audible. Audible products included oral versions of books and newspapers. The acquisition gave Amazon’s 16 million plus customers’ access to 20000 hours of Hi-Def audio content from newspapers, magazines and books that had been available only to Audible customers. So, basically, Amazon scaled up on its current operations to add huge sales content [25].

7. Learning options:

R & D investment to explore different technologies may provide the learning needed to enhance business capabilities. As was said earlier, positive NPV's are not the only criteria to consider.

An example of learning option: Many companies invest in building product prototypes in order to gain better understanding of consumer acceptance which also allows them to gain quality feedback to improve the product. These companies invest in multiple prototypes but seldom gain money from making prototypes but rather the information gained from these prototypes, which is used in making the final product "better". So making of prototype is a learning option.

It is often even better to learn about ones competitor's moves in order to make decisions. Kim and Sanders [21], suggest a diagram for making strategic actions in IT investment decision making.

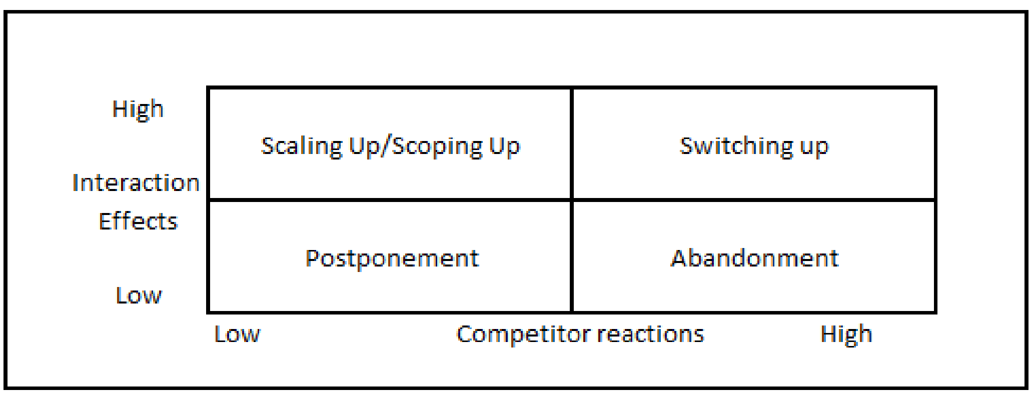


Figure 1 Strategic actions in IT investment decision making. [21]

The above frame work as shown in Figure 1 explains how decision makers react in a competitive environment with real options [21]. Interaction effect means the chance of pay off expected by the decision maker. So high interaction would mean chances of high payoff and low interaction means chances of low pay off. In the framework, competitor reaction means the moves that competitors are making in parallel to the decision makers move. So high competitor reaction would mean that a lot of similar activity is being pursued by the competition and low competitor reaction would mean that competitors are not pursuing a parallel option or are not very interested in it at the moment. Therefore when competitor reactions are low, as are the interaction effects, the decision maker can wait for more information before taking an action, a scenario that would resemble a deferment or postponement option. In the case when competitor reactions are high and interaction effects are low, the decision maker can choose to abandon the project completely.

Scoping up and switching up represents two different types of growth options. When competitor reactions are low and the interaction seems to be high, it gives the decision maker the first mover opportunity to exploit the option before competitors catch up to it. Thus a switching up option is basically a combination of a growth option and an abandonment option. When both competitor reactions and interactions are high, a switching up option can be used. In this case the pay off may be lower due to the fight for bigger market share between the competitors. But the decision maker can abandon the current project and use the information gained from it to start a new one.

Even though this framework suggests a basic strategy for companies to deal with the afore mentioned situations, the decisions are heavily dependent on the business capability of an organization. Business capability provides the decision maker with the basic knowledge he needs to formulate options for the decision's he might have to take. In the next section literature on business capability is reviewed.

2.4 Business Capability

Business capability is a distinctive attribute of a business unit that creates value for its customer. It is measured by the value generated for the organization through a series of identifiable cash flows. [26]

Capabilities are the sole factor that differentiates one business from others. Researchers claim that business capability and core competency are the same concept that makes a business unit unique [26]. Prahalad and Hamel, suggest that core-competence emphasizes technological and production expertise that is meant to explain a company's myriad of product lines, but cannot fully explain how companies successfully move into wide ranges of businesses [27].

Business capability can be explained as the way value is generated by a firm which is impacted by the firm's market conditions, as well as its policies and strategies and operating drivers, as explained in Figure 2.

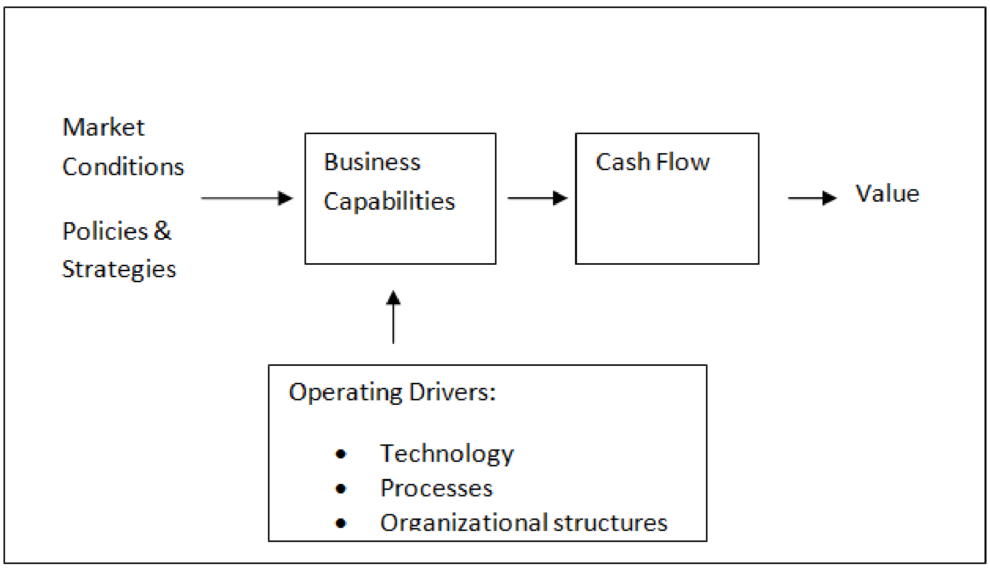


Figure 2 Transformation of capabilities into value diagram [26].

The production function consists of operating drivers rather than a simple investment in technology. Thus a collection of operating drivers together with the way they are deployed, give the firm its "business capability". So business capability becomes a function of market conditions, policies & strategies and the operating drivers of technology, processes and organizational structure. An organization adds value by generating profitable cash flows using its business capabilities.

The job of an engineering manager is thus to identify positive market conditions and supporting policies and also to lay a wager on the firms' operating drivers to generate value while understanding the risks involved with the particular decision.

It is often believed, that exercising options can have positive impacts like gains in market share in the future or gains in competitive advantage in the future. The dilemma faced by decision makers is that such gains are very hard to quantify or evaluate in numerical terms, as has been expected by the traditional DCF type of valuation procedures [26].

Balasubramanium et al. [26], suggest some valuation techniques to address this dilemma. They suggest that the choice of analytic method depends on the source of risk (See Table 1).

Table 1: Risk Evaluation Techniques [26].

Source of Risk	Information required to value contingent claims	Analytic method
Prices of market- traded securities	Current prices, volatility	Black-Scholes and other financial option pricing models
Product/service or input market-related risk (e.g. prices of goods and services, market size)	Traded prices as proxies, volatility of proxy variable OR Actual growth rate, measure of systematic risk (b), volatility and convenience yield of the risky variable	Risk-neutral "Decision trees" (e.g. binomial models)
Unique events affecting the firm (project-related risk)	History-based subjective probability estimates of events	Risk-neutral decision trees

Using these measures engineering managers can reexamine the transformation of capabilities into their value equation. Engineering managers can estimate the uncertainty presented to the firm by market conditions with respect to policies and strategies using risk neutral probabilities. The uncertainty presented by the operating drivers can be represented by using the firm's own risk probabilities and utility functions. In doing so engineering managers can truly estimate the value of the decision.

3.0 Methodologies used to calculate capital budgeting and option values.

3.1 Traditional criteria.

3.1.1 Discounted Cash flow analysis:

The DCF method is widely used in the finance sectors by investment corporations and banks, real estate development corporations, and institutions. DCF uses the concepts of the time value of money for valuing a project, investment, or an asset. In this method all the future cash flows are discounted to the present time. And the sum of all these cash flows, balanced against a present time investment, becomes the Net Present Value of the cash flows under consideration.

Mun has pointed out some disadvantages of the DCF methods in [28], and they lie in the assumptions on which the DCF methods have been developed. He argues that although DCF methods are easier to compute they do not always reveal the true picture as stated in Table 2, which is reproduced from this manuscript [28].

Table 2: Disadvantages of DCF method [28].

Disadvantages of DCF method	
DCF Assumptions	Realities
Decisions are made now and cash flow streams are fixed for the future.	Uncertainty and variability in future outcomes. Not all decisions are made today, as some may be deferred to the future, when uncertainty resolves.
Once launched, all projects are passively managed.	Projects are usually actively managed throughout the project life-cycle, including check-points, decision options, budget constraints etc.
Future free cash flow streams are all highly predictable and deterministic.	It may be difficult to estimate future cash flows as they are usually stochastic and risky in nature.
Project discount rate used is the opportunity cost of capital, which is proportional to non-diversifiable risk.	There are multiple sources of business risk with different characteristics, and some are diversifiable across projects or time.
All risks are completely accounted for by the constant discount rate.	Project risk can change during the course of time.
All factors that could affect the outcome of the project are reflected in NPV.	Project complexity and so-called externalities make it difficult to quantify all factors in terms of incremental cash flows. Disrupted, unplanned outcomes can be significant and strategically important
Unknown, intangible or immeasurable factors are valued at zero.	Many important benefits may be intangible assets or qualitative strategic positions.

3.1.2 Internal Rate of return:

Internal rate of return (IRR) is the discount (interest) rate at which the net present values of the project, both positive and negative, are zero. Typically projects with higher IRR are chosen over the projects where the IRR is lower. The advantage in using this method is that it allows the decision makers to determine the financial feasibility of projects without having to choose an appropriate discount rate as in DCF methods. IRR has an advantage when the comparison is being done between projects with similar objectives. But nonetheless IRR suffers from all the flaws of DCF as described in the earlier table.

3.1.3 Black and Scholes model:

The Black and Scholes model is one of the most important concepts in modern financial theory. It was developed by Fisher Black, Robert Merton and Myron Scholes in 1973 [8]. Their model was designed to be used for pricing of European style call options.

The Black-Scholes formula calculates the price of a call option to be:

$$\mathbf{C = S\ N(d_1) - X\ e^{-rT}\ N(d_2)} \qquad \text{(E1)}$$

Where,

C = price of the call option

S = price of the underlying stock

X = option exercise price

r = risk-free interest rate

T = cumulative time until expiration

N () = area under the normal curve

$d1 = [\ \ln(S/X) + (r + \sigma^2/2)\ T\ ] / \sigma\ T^{1/2}$

$d2 = d1 - \sigma\ T^{1/2}$

σ = the volatility in the returns of the underlying asset

Similarly for a put option the value of the put option can be written as the following mathematical equation:

$$\mathbf{P = Xe^{-rT}N(-d_2) - S\ N(-d_1)} \quad \text{(E2)}$$

The DCF approach treats projects as independent investment opportunities which are under taken if the NPV is positive, and rejected if the NPV is negative. This decision making is done on the basis of future predictions which are uncertain.

Since the DCF approach fails to capture the true flexibility in the decision making process, an organization may refrain to invest in a project where DCF type of valuations show the investment to be ‘out of the money’ in a non-stochastic environment. Many organizations attempt to account for failure costs i.e. sunk costs, but again such accounting often fails to capture the true flexibility of the decision making process.

3.2 Comparing DCF analysis to Black-Scholes method of valuing options.

Using a numerical example explained by K.T. Yeo, Fasheng Qiu [20] one can compares the traditional DCF methods to Black and Scholes method.

Suppose ‘ABC’ automobile company wants to invest into the Chinese automobile market. They would like to buy into an established Chinese automobile company Z which is willing to transfer its ownership to a foreign company. Suppose the valuation of the company Z worthies assumed to be $ 460M (I^0). Assuming that with no follow up investment the company Z will generate revenues for at least 3 years. Table 3 shows the estimation of cash flows for company Z.

Table 3 Cash Flow Analysis. (Acquisition of company "Z") [20].

Cash flow analysis (NPV is calculated with annual discounted rate of 25%) (Value in millions)								
				(r=0.25)				
Yr.	Revenue	Cost	Profit	NPV	I^1	NPV (I^1)	V^1	NPV (V^1)
				Net present value of profits	Future investment	Net present value of future investment	Value ascertained after future investment	Net Present value of future valuation
1	$900	-$870	$30	$24.0				
2	$950	-$930	$20	$12.80				
3	$1,100	-$500	$600	$307.20	$1,000	**$512**	$1,200	**$614.40**
				$344				

After 3 years, ABC has an option to invest an additional $1B ($I^1$), to expand its production line, which may generate profit and lead to a sustainable business with a market value of $1.2 B ($V^1$). The weighted average cost of capital of the company is 25%. This is the appropriate discount rate used by the company.

Using the DCF analysis (assuming this is an irrevocable commitment), the value after the second stage expansion of the company is:

Net present value (NPV) gain (loss) from the investment = ∑ (NPV from year 1, 2 & 3)

– NPV of future investment + NPV of gains from future investment

NPV = NPV Yr. 1 + NPV Yr. 2 + NPV Yr. 3 + $(1200\text{-}1000)/(1+0.25)^3$ = $ 446.2 M

Now the valuation of the decision would be = Initial investment – NPV gain (loss) from the investment

The valuation of acquiring company Z = NPV (Z) - I^0 = 446.2 – 460 = -$ 13.8 M

So, according to the DCF analysis, acquiring Company Z would result in negative value and thus the decision is ‘out of the money’, and thus should not be taken.

Now using the Black and Scholes model to evaluate:

Using Black and Scholes’ method, the option to expand at the 3rd year is similar to a call option, i.e. the company has the right to deny/defer or go ahead with the second stage expansion.

Now the net present value of the follow up investment is the initial value: S = $614.4 mil and the strike option X = $1B. Time for maturity T = 3 Years. Assuming volatility of the automobile market as 50% this sets $\sigma = 0.5$. Assuming risk free interest rate is 5%. Using the Black and Scholes formula, the second stage call option value C would be found to be $ 140.23 M.

The value of the option C relies on σ, the volatility of the automobile related stock value V(S), and on T, the option’s cumulative time to maturity. The asymmetrical distribution of V, as illustrated in Figure 3, also implies that the upside potential is good with higher option value, C, with increasing σ (and risk) and T. [20]

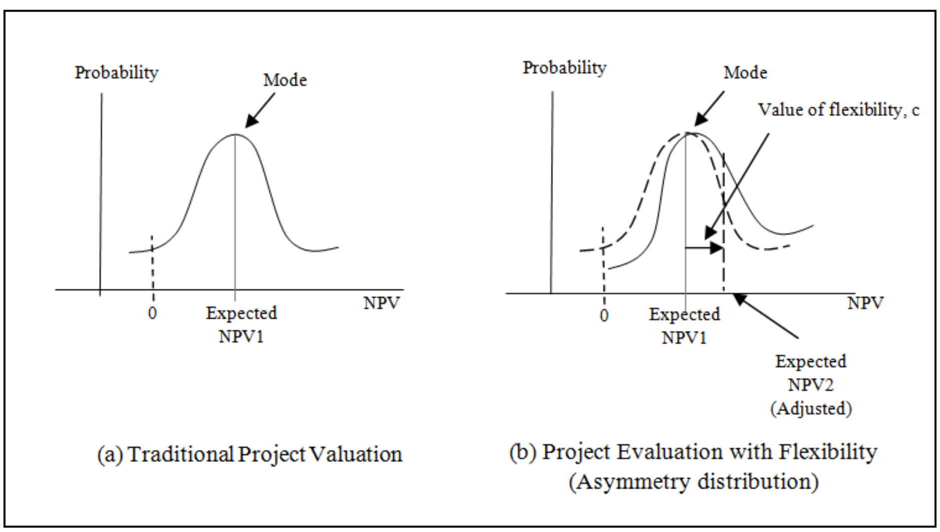


Figure 3 Value of managerial flexibility [2017].

So the value of the acquisition should be the sum of NPV's for the first 3 years and the option value is calculated as:

Thus $NPV(Z)^{option} = NPV1 + NPV2 + NPV3 + C = \$ 344.0\ M + \$ 140.23\ M = \$ 484.23\ M$

So the net present value of acquiring the company = $NPV(Z)^{option} - I^0 = \$ 484.23\ M - \$ 460\ M = +\$24.23\ M$

Reviewing then, when the decision to acquire company Z was valuated using the traditional DCF method it would be rejected because the future investment would have been considered definite but with the Black and Scholes method it was found to be represent a positive decision since the future investment was treated as an option and this future commitment of funds is only made if it is favorable "at the time".

Thus using options pricing evaluation, the engineering manager can more effectively account for organizational flexibility and an option valuation would represent a more realistic estimate of a potential project undertaking.

3.3 Understanding Option Pricing Valuation and Decision Tree Analysis (Incorporating a utility function)

In the options pricing literature, Trigeorgis et al. [29], Mason et al. [30], and Copeland et al. [31], have argued that option pricing methods are superior over other decision analyses. Smith and Nau in their paper [32], have compared options pricing analysis and decision tree analysis and have conclude that both of these methods are consistent in all types of market conditions (Complete market condition, incomplete market condition and partially complete market condition).

Smith and Nau use the same example, discussed later, as used by Trigeorgis et al. [29], Mason et al. [30], and Copeland et al. [31**Error! Bookmark not defined.**], to develop a decision tree. The urpose of using the exact same example is to reject the claim of Trigeorgis et al. [29], Mason et al. [30], and Copeland et al. [31], that option pricing method is superior to decision tree analysis. Smith and Nau, assert that decision tree analysis is as robust as the option pricing methods if market opportunities to borrow and trade are included in the decision tree analysis and if time and risk preferences are captured using the decision makers utility function. Smith and Nau also show that option pricing techniques and decision tree analysis can be successfully integrated for analyzing investment decisions.

The following section will describe the way Smith and Nau have used decision tree analysis and option pricing methods to analyze the investment decision by incorporating the firm's utility function that captures the firm's subjective time and risk preferences.

The Investment example: Option to invest in a plant

The example that Smith and Nau analyze in their paper [32], is of a firm which has a choice of investing in a 'plant for $104' with a prevailing market risk rate of 8%. *(The monetary values used in this example are not real but scaled down representative values, for the ease of explanation).* The firm faces the decision to invest in the plant or not as the firm is uncertain about future market conditions. Favorable market conditions would result in a positive value for the firm where as unfavorable market conditions would result in loss. In order to create a simple example, it is assumed that the decision makers have 3 options described following:

Option 1: Invest now alternative

Under this option the firm will have to invest $104 immediately. The cash flows generated from the investment would be realized after a year. However, depending on the conditions prevailing in the market, the value of the cash flows would be affected. Smith and Nau, for simplicity, have chosen two possible market conditions. One being a 50% probability that the market conditions would turn out to be good, resulting in $180 worth of positive cash flow and the other condition (50% probability) being that if the market conditions turn out to be bad, the cash flow would be only $60.

Option 2: Defer alternative

If the firm wants to defer building the plant they can wait for a year after they purchase a lease/license to build the plant. This lease/license would allow the firm to defer its investment for a year. They assume the cost of building the plant would go up by (a risk free rate of) 8% so they would have to invest $112.32 but the cash flows of $180 (good) and $60 (bad) would result in $67.68 *($180 - $112.32)* and -$52.32 *($60 - $112.32)* for good and bad conditions. Also in the defer alternative the firm will retain the decision to decline to invest at the end of this year.

Option 3: Decline option

Decline to invest in building the plant resulting in a $0 payoff.

The simple decision tree for the investment example:

Figure 4 represents the decision tree that can be drawn for the investment example incorporating all the three options that the decision makers face.

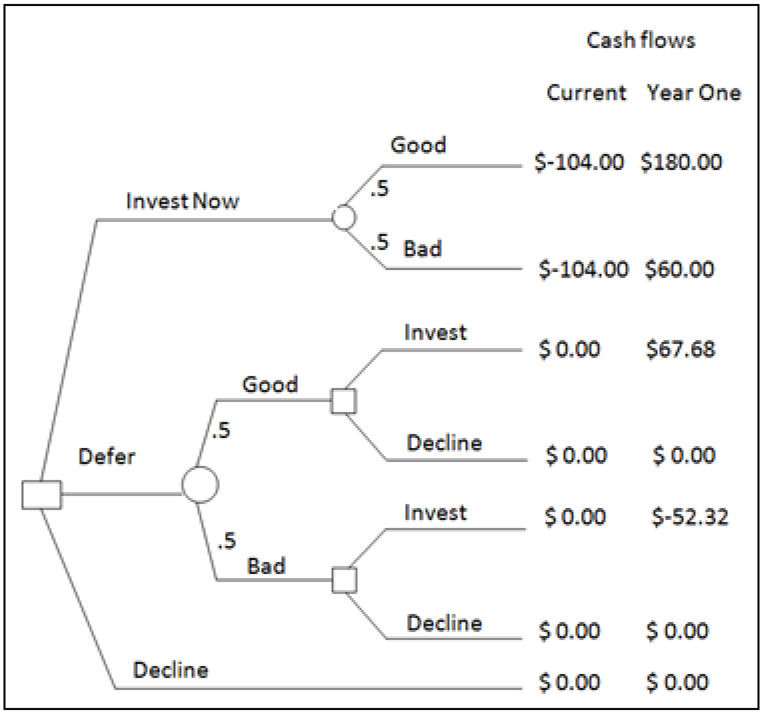


Figure 4 Decision Tree for the investment example.

Traditionally, a decision tree would be evaluated to find the most beneficial option which would be selected. But Smith and Nau are of the opinion that it is important to include trading strategies in the decision tree. The following section will discuss how such trading strategies can be incorporated in the decision tree analysis.

Incorporating market opportunities to trade and borrow, and using a firm's utility function to capture time and risk preferences:

Smith and Nau say that the key to making a robust decision tree is to explicitly recognize and incorporate market opportunities in the decision analysis model and establish the relationship between the various opportunities a firm may have [32].

To capture market opportunities to trade and borrow, Smith and Nau use a twin security. They assume that there are two securities in the marketplace. A risk free security that allows the firm to borrow and lend at 8% and a twin security, (*Twin security is a type of security that is traded in the financial markets and has the same risk characteristics -- i.e. perfectly or high correlated -- as the project under consideration -- Pay offs of the project. The existence of a twin security is implicitly assumed in the traditional DCF analysis for estimating the required rate of return on a project.*), whose future values depends on an uncertain level of demand, as shown in Figure 5. Smith and Nau assume that the price of the twin security is $ 20. In the 'good state' the twin security would yield $36 and in the 'bad state' it would yield $12.

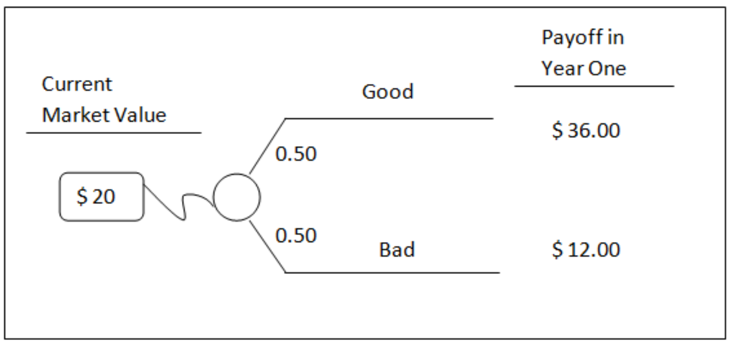


Figure 5 Twin security pay off decision tree [32]

Now if one looks at the Twin security, its payoffs are directly proportional to the pay offs of the invest now option of the project ($36 = 1/5 * $180 and $12 = 1/5*$60), thus one can conclude there should be an appropriate market risk rate that is equivalent to the risk involved in the invest now option of the project being evaluated. [32].

In theory, in the options pricing method, a portfolio of securities is usually considered rather than seeking out a single twin security to accurately represent equivalent pay offs between the project and the securities. So building on the earlier twin security example, if the firm buys 5 twin securities: Investment would be 5 x $20 = $100 and pay offs would be good => 5 x $36 = $180 and bad => 5 x $12 = $ 60. The underlying assumption was, ***"the price the project would have if it were traded"*** …… (Mason and Merton, 1985, pp. 38-39) [30].

In order to include the trading opportunities in the decision tree, Smith and Nau have tried derived mathematical equations where trading opportunities are recognized. The following section discusses how the Smith and Nau have derived those equations.

They assume that a firm is considering a project "c" and also has the options of investing in a portfolio of securities of which some are risk free securities and some are twin securities.

If the firm undertakes the project and invests in the securities, following a trading strategy β_p, its time t cash flows can be mathematically represented by the following function (E3): (Smith and Nau, 1995, pp. 800-802) [32]

$$X_p(t;\beta_p) = c(t) + [\beta_p(t-1) - \beta_p(t)]s(t) \qquad \text{(E3)}$$

If the firm declines to invest in the project and follow strategy $\beta\bar{p}$ its time t cash flow is given by the following equation (E4): (Smith and Nau, 1995, pp. 800-802) [32]

$$X\bar{p}(t;\beta\bar{p}) = [\beta\bar{p}(t-1) - \beta\bar{p}(t)]s(t) \qquad \text{(E4)}$$

Where

$X(t,\beta)$ – cash flow at time t for the strategy β

$c(t)$ – the project

$s(t)$ - Cost of securities at time t under the state of nature $\acute{\omega}(t)$.

β_p – Trading strategy to invest in project c and in securities

$\beta\bar{p}$ – Trading strategy to invest just in securities.

The breakeven buying price is defined as the lump-sum, time-0 payment $\mathbf{v_b}$, that makes the maximum expected utility from the project equal to the maximum expected utility without the project. So for the indifference point the maximum expected utility with the project equal to the maximum expected utility without the project.

Therefore indifference points can be expressed as equation (E5): (Smith and Nau, 1995, pp. 800-802) [32]

$$\max_{\beta p} E[U(x_p(0;\beta_p) - \nu_b, x_p(1;\beta_p), \ldots\ldots\ldots\ldots (x_p(T;\beta_p))]$$

$$= \max_{\beta \bar{p}} E[U(x\bar{p}\,(0;\beta\bar{p}) - \nu_b, x\bar{p}\,(1;\beta\bar{p}), \ldots\ldots\ldots\ldots (x\bar{p}\,(T;\beta\bar{p}))] \quad \text{(E5)}$$

Similarly the breakeven selling price $\boldsymbol{\nu_s}$**,** is defined analogously as equation (E6): (Smith and Nau, 1995, pp. 800-802) [32]

$$\max_{\beta p} E[U(x_p(0;\beta_p), x_p(1;\beta_p), \ldots\ldots\ldots\ldots (x_p(T;\beta_p))]$$

$$= \max_{\beta \bar{p}} E[U(x\bar{p}\,(0;\beta\bar{p}) + \nu_s, x\bar{p}\,(1;\beta\bar{p}), \ldots\ldots\ldots\ldots (x\bar{p}\,(T;\beta\bar{p}))] \quad \text{(E6)}$$

Now using the equations representing the cash flows, for the firm choosing to go ahead with the project or declining to invest one can calculate the payoffs in the decision tree for building the plant.

In the case where the firm is considering building the plant Smith and Nau have assumed that the firm's time and risk preferences are captured by the utility function, which is concave in nature. The utility function thus can be written as: (Smith and Nau, 1995, pp. 800-802) [32].

$$U(x_0,x_1) = -e^{(-x0/R1)} - e^{(-x1/R2)} \quad \text{(E7)}$$

x_0 and x_1 are cash flows at time 0 and time 1, and R_1 and R_2 are two numeric values representing risk tolerance of the firm. "The utility function is strictly concave in (x_0, x_1), and continuous and strictly increasing in x_0 and x_1, in the neighborhood of $(x_0, x_1) = (0, 0)$, the firm is indifferent between \$1.00

at time 0 and $1.10 at time 1, implying a marginal time preference captured by a 10% discount rate" [32].

R1 = 200, R2 = 220, For example: To calculate the utility value of the 1st branch in the decision tree shown in Figure 6, using equations (E5) and (E6), x_0 = 105.90 -104.00 and x_1 = 180 -132.85.

Using this information one can construct the modified decision tree, as shown in Figure 6.

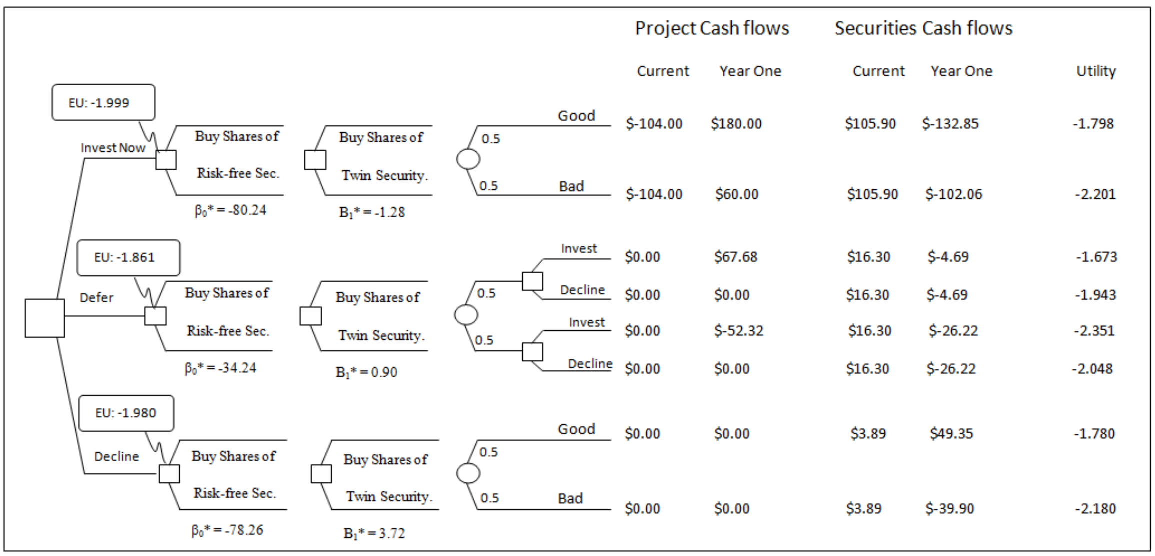
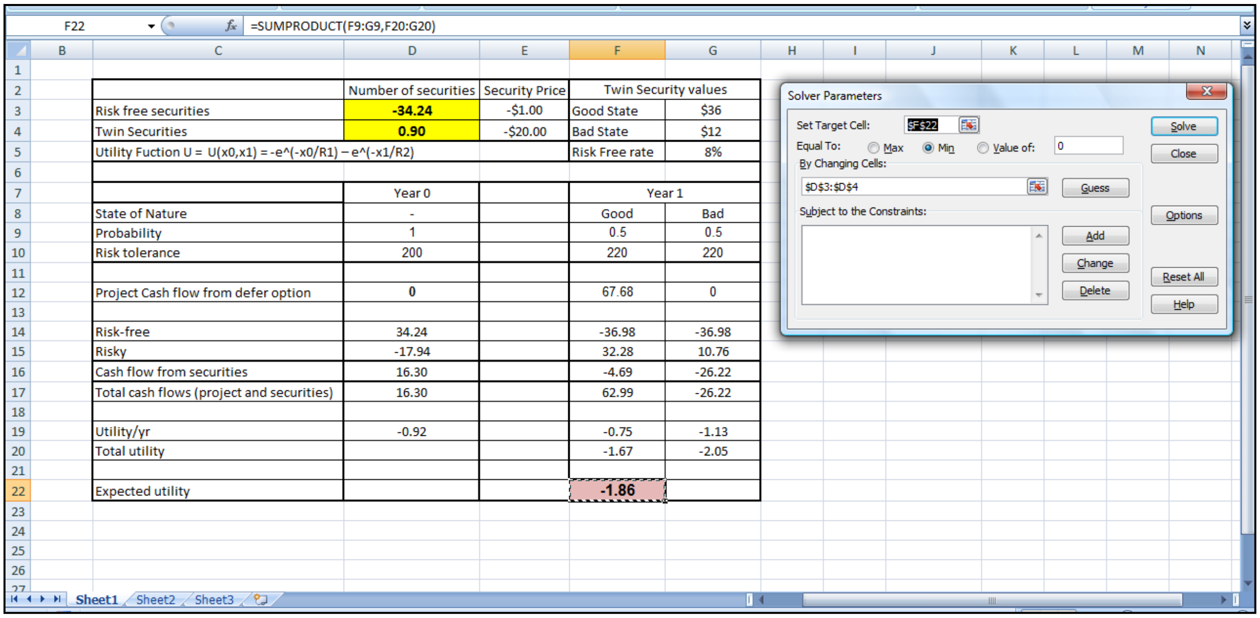


Figure 6 Modified Decision Tree [32].

Using the pay offs from the decision tree one can calculate the amount of risk free and twin securities that a firm would need.

Calculation example: For Option 2: Defer option

To determine the optimal security purchases that can be traded with the construction project, a solver model had to be created. The objective function was to minimize the utility, and the changing cells were the number of risk free securities and the number of twin securities. Figure 7 is a screen capture of the modeling of the problem on MS Excel 2007.



	Number of securities	Security Price	Twin Security values	
Risk free securities	-34.24	-$1.00	Good State	$36
Twin Securities	0.90	-$20.00	Bad State	$12
Utility Fuction U = U(x0,x1) = -e^(-x0/R1) – e^(-x1/R2)			Risk Free rate	8%
	Year 0		Year 1	
State of Nature	-		Good	Bad
Probability	1		0.5	0.5
Risk tolerance	200		220	220
Project Cash flow from defer option	0		67.68	0
Risk-free	34.24		-36.98	-36.98
Risky	-17.94		32.28	10.76
Cash flow from securities	16.30		-4.69	-26.22
Total cash flows (project and securities)	16.30		62.99	-26.22
Utility/yr	-0.92		-0.75	-1.13
Total utility			-1.67	-2.05
Expected utility			-1.86	

Figure 7 Solver modeling (Defer Option)

Thus from the calculation its can be said that, β_0 = -34.24 (or -$34.24 worth of risk free shares) and β_1 = -0.9 shares.

This means the firm would be borrowing $34.24 of risk free securities and buying 0.9 shares of the Twin security, if the firm goes for the “Defer Now option” option.

The expected utility values for each of the branches of each option were calculated using the utility function as defined earlier. From the decision tree (Figure 6), the least negative expected utility value for the firm is along the defer option branch. (In the calculations the cost for obtaining the license to defer was considered to be zero!). Thus by incorporating trading strategies along with the decision tree analysis not only makes the tree robust but also provides a clear view to the decision maker.

4.0 Application of Real Options to Technical Management Decisions

4.1 Defining Options in Technology Management decisions (When can a company Use Options Theory)

"What is and what is not a real option?" is a question an engineering manager should be familiar with. The ability to distinguish between a real option process and a sequential decision making process may impact the decisions of an investment options continuation/further exploration/holding or abandonment.

4.1.1 Understanding the boundaries of Real options

The boundaries of real options are often considered in relation of the breakdown of net present worth in such a way that investment choices have properties of high uncertainty and reversibility. A real option analysis in contrast with a net present value analysis provides better characterization of the investment's true value because of the NPV analyses inability to account for the value of delaying any potential future commitment [33].

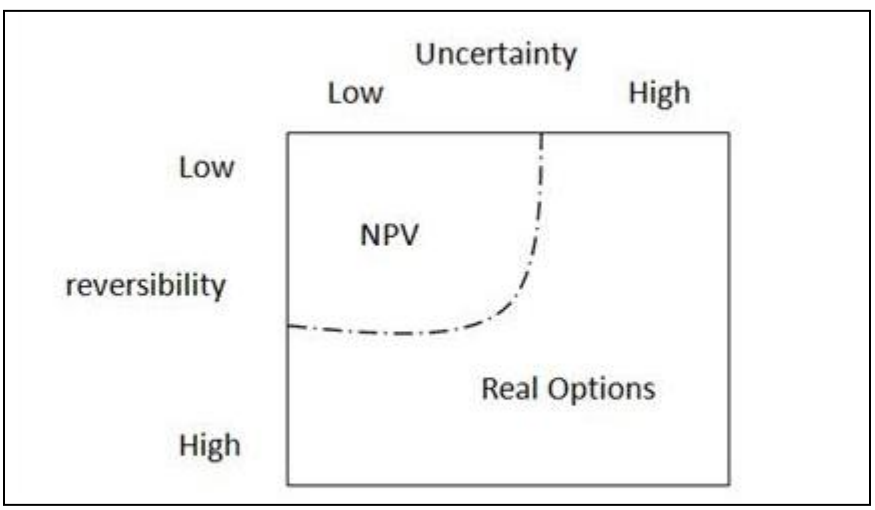


Figure 8 Boundaries of Applicability for Net Present Value and Real Options.

As one moves from real options based on tradable assets where the firm has no hand in resolving uncertainty and the set of possible actions in response to the uncertainty can be set at the time of initial investment, towards real options on strategic opportunities, (like investing in developing of new technology or emerging technologies). In such strategic opportunities the outcomes are very much dependent upon the firm's actions and outcomes linked to firm's actions. Thus the clear demarcation begins to blur and the application of a real option methodology becomes more and more, challenging [33]. (See Figure 8)

As target markets and technical agendas become more flexible the discrete investment logic of real options becomes eroded, and activities may be characterized as sequential path dependent processes (See Figure 9). Alternatively if the scope of the real option is fixed prior to the investment, meaning if the opportunities where the option is to be exercised is specified at the start of the investment, then the decision to abandon an initiative can be clearly articulated and the flexibility associated can be controlled and maintained readily. [33]

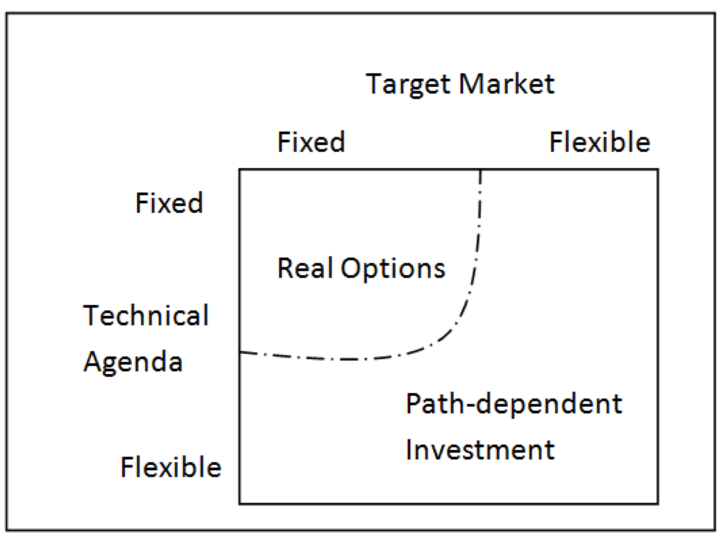


Figure 9 Boundaries of Applicability for Real options and Path-Dependent Opportunities [33].

But imposing rigid boundaries of conditions of an abandonment option may lead to underutilization of discoveries made in the context of failures with respect to their initial agenda but that introduce promising possibilities not previously imagined [33]. This highlights the need for a more nuanced organizational perspective that incorporates the different views that exist within an organization.

4.1.2 Arguments against Levinthals and Inseads's Approach [3333]

McGrath, et. al. [11], in their paper argue that Levinthals and Insead's [33] claim that situations with flexible market application and/or flexible technical agendas do not offer an option value. They argue that flexible by definition suggests future choices. In support of their argument they quote March's [34] views in his paper, that exploration in uncertain areas is strongly associated with heterogeneity in resource accumulation, creating the potential for preferential access.

McGrath, et. Al. [11], Argue that Levinthal and Insead [33], assume that without rigidly defining criteria for success and failure of an initiative abandonment option cannot occur. They say that achieving "Flexibility" is more to do with effective project management and appropriate organizational structure than with inadequacies in or misapplication of real options theory. They view defining a success or failure criteria as one of the practices in order to manage flexibility of an initiative.

4.1.3 Reasons for setting a fixed failure and success criteria at the outset of an initiative as described by Levinthal and Insead [33]

a) Challenges of the abandonment option:

Options are flexible not because they substitute a stream of smaller payments for a larger lump sum payment but because the payment stream can be abandoned in the light of negative outcomes or continued otherwise. The more poorly defined the abandonment option is, the less valid is the perception of flexibility and the less appropriate the nominal application of real options logic. Firms face an organizational challenge to exploit the flexibility offered by the sequential nature of option like investments if there is no proof of failure or strict and structured abandonment deadlines specified. This is especially true even if some technology has not yielded the desired results, but it cannot be proven that the technology is incapable of succeeding [3333].

The abandonment option becomes more problematic in the face of options on strategic opportunities that do not have an explicit, exogenous expiration date. How long should the firm pursue the option is often difficult to specify, As people over weigh outcomes that are considered certain, relative to outcomes which are merely probable [35], the possibility of a failed project succeeding in some other environment, or market cannot be completely ruled out.

b) Organizational factors

There are significant organizational and financial costs associated with holding options hence it becomes more and more important to manage the abandonment of options. The challenges related to the abandonment option are further complicated by the nature of organizational resource allocation and the different perspectives and incentives of the stakeholders at different level of the organization [36]. Along with these factors the challenge is further compounded by the psychological deterrents.

4.2 Escalation of commitment in the absence of clearly defined abandonment options. (Psychological deterrents)

Zardkoohi [37], suggests that unconstrained real options can lead to an escalation of commitment. Levinthal and Insead [33], suggest that real options are better than financial options, but one of the problems is that the firm’s investment decisions might fail to follow a strict real options frame work: that is that the option may be exercised even when the event did not materialize. The reason being that decision maker’s psychological situations deter them from making the correct decision.

Levinthal and Insead [33], suggest that management might systematically pursue failed strategies because:

- Problems precluding that the strategy might prove successful in some other later market.
- The manager in charge might be so focused on the investment that he or she might not be aware of the large set of alternatives available to the firm.
- Of career consequences that associated with the abandonment option.
    - Of difficulty the firms have incorporating the logic of sunk costs.
    - Of the political impetus not to show failure.
    - Of the natural desire to succeed.

4.3 Organizational deterrents: Escalation of commitment in the absence of clearly specified abandonment conditions [37]

4.3.1 Issue 1: Tragedy of commons

"Tragedy of commons" is also known as "fallacy of composition" or "prisoners dilemma" it is actually a situation where the benefits of an action are accrued to the decision maker, whereas the costs are diffused [37].

Zardkoohi suggests that the option, even when proving to be a failure, is pursued often as the resources used, unjustifyingly, might not directly affect the decision maker. If the investment proves successful the credit would go to the decision maker but the losses incurred are diffused to the all organizational members involved. This is the so-called "tragedy of commons" [37] where blame is shared commonly while success is unique.

The explanation Zardkoohi gives is: "The higher the proportion of the costs of a failing project can be passed onto others outside the decision maker's organization, the higher the probability that escalation of commitment will occur, all else being constant [37]".

Staw & Ross explain the dilemma as, *"Escalation would be expected in situations where the allocator of funds to a project can take credit, but any costs or losses would be absorbed by a larger department or the organization as a whole"*. [38].

4.3.2 Issue 2: Psychological, Social and Occupational Justifications

Research done by Staw [39] in a laboratory setting suggests that subjects allocated significantly more resources to failing systems compared to the highly performing decisions or situations. He also found that if the person is involved in initial allocation decisions in failing divisions they subsequently allocated more resources to the option than a decision maker who was not responsible for the initial allocation decision. Staw & Ross [39], suggest that individuals responsible for a failed course of action may seek to justify their action by escalating their commitment to it.

Staw & Ross [38], explain that social face saving may be responsible for these subjects to act in this pattern. The decision makers might pursue a failing strategy because they want to avoid revealing their errors to others. They say that this behavior implies that escalation of commitment may be more prevalent in partnerships than in private proprietorships. A partner may have a greater inclination to escalate a decision to a failing venture just to avoid loss of face before his other partners.

Zardkoohi [37], makes the following supposition: "The greater the effects of economic (or project) and structural considerations, the lower the effects of psychological and social factors on the decision to escalate commitment to failing strategies".

Occupational justifications are more justified by the skill of the decision maker. Zardkoohi [37] explains that managers with company specific skills create more value in their current organization than in other organizations. Thus managers with a company's specific skills have more incentive to stay in their current organization while moving to another organization might imply loss of significant value, when compared to managers with general skills.

Managers with company specific skills are more prone to escalation commitment to failing strategies than managers with general skills.

Zardkoohi [37] makes the further supposition: “The greater the degree of firm-specific human capital of the manager/decision maker, the greater the degree of escalation of commitment when the organization experiences strategic failure.”

An alternative to the above proposition is that, when prior decisions cause systematic failures the organization considers pursuing alternative strategies. Many researchers suggest that strategy is an emerging process, and involves decision makers at multi levels. Generally an organization has a three level hierarchy: front line or bottom level managers/decision makers, the middle level managers/decision makers and the top management. The extent a corporations strategy is formed through an emerging process helps to mitigate the organization’s tendency to escalate commitment towards a failing project.

Zardkoohi [37] makes another supposition: “Organizations that adopt an emerging and competitive process of strategic formulation and implementation, escalate commitment towards successful strategies and against failed strategies.”

4.3.3 Issue 3: Prospect Theory

Kahneman & Traversky [35], purport that, “people over weight outcomes that are considered certain, relative to the outcomes which are merely probable”. Laboratory research suggests that people value a certain outcome more compared to an uncertain one and conversely the loss of a certain outcome causes more displeasure compared to the loss of one which was highly uncertain. Prospect theory evaluates gains and losses incurred from a subjective reference point.

Since one loss is accorded a higher level of guilt compared to another alternative , prospect theory predicts that when people face two alternatives with the same expected value they would choose the more uncertainty over the more certain alternative (i.e., they would become risk takers).

Thus when it comes to managers using a real options approach, a failing strategy would present more risk and prospect theory suggests here that the escalation to commitment may occur as the failing strategy offers more uncertainty over a certain outcome (like backing out). This behavior is similar to the case of gambling, for example when a gambler chooses to make escalated risk commitments even during a losing streak of deals.

4.4 Application of Real Options Example: Numonyx Acquisition by Micron Technology, Inc. (A business case)

4.4.1 The Acquisition

American memory maker Micron Technology Inc. (MU) announced on May 7th 2010 that it had completed the acquisition of Numonyx B.V in an all stock transaction. Micron issued 138 Million shares of MU common stock to Numonyx Share holders, Intel and STM electronics, N.V. and Francisco partners and assumed outstanding restricted stock units held by Numonyx Employees. [40]

In the companies' Q4 results of 2010, the amount paid to Numonyx as declared by MU was $1.112 bn.

About MU:

As disclosed in its results for the second quarter of fiscal 2010 on Mar 31st 2010 the company states, "Micron Technology, Inc is one of the world's leading providers of advanced semiconductor solutions. Through its worldwide operations, MU manufactures and markets DRAM, NAND flash memory, other semiconductor components and memory modules for use in leading edge computing, consumer, networking and Mobile products"

About Numonyx:

Numonyx Holding B.V. was founded in 2008 by Intel and STMicroelectronics. The two core technologies of Numonyx were NOR and NAND flash memory devices. NOR flash is used in many mobile phones, whereas NAND flash is becoming more and more popular in storage arrays, servers, desktops, notebooks, net books, mobile Internet devices and is also used in mobile phones, as well as the ever-present USB sticks and camera cards. Also Numonyx had been developing a new type of memory known as Phase change memory. Numonyx had revealed a prototype of the memory in Nov 2009 but did not mention as to how long it would take for them to make this new technology available commercially. [41]

4.4.2 Non-volatile memory Market structure:

The Non-volatile memory segment is a very dynamic segment of the semiconductor market. Today product designers (Memory market customers – computing device makers) have a wide variety of choices when it comes to selecting a memory architecture from various options that are available to them in the market. The significant share of these choose NAND & NOR memories. NAND memories choices are more significant and have a higher market growth rate as compared to NOR memories. Since each of these memories types offer some advantage, in certain areas, they are preferred over the other choices for their unique characteristics. But combined together these are sold to consumer electronics manufacturers, PC manufacturers, Data storage manufacturers, embedded solutions for industrial and automobile companies, mobile devices etc. Sometimes these technologies are competing amongst themselves thus making this market very "cut throat" on the two levels of price and performance.

Major competitors in this market are SSD (solid state drives), NAND and NOR OEM (original equipment manufacturers) manufacturers like Samsung, MU, Hynix, Elpida, Toshiba, Intel and a few others. Apart from these OEM's there are certain major third party manufacturers like fusion-IO, OCZ, Virident and Western Digital etc. Among all these companies, Intel and Samsung lead market share with MU following a close third [42].

4.4.3 The opportunity to acquire Numonyx.

The first time the Numonyx deal was mentioned by company outsiders/analysts was in early Feb., 2010 by *Electronic Engineering Times*. (EEtimes.com), a leading online news and analysis website focusing on developments in the electrical and electronics industry, revealed that there were rumors about MU being in talks with Numonyx to acquire it wholly. [43]

The opportunity offered by Numonyx was not that great if the deal was considered from a pure (Traditional) economic point of view. Numonyx sold NOR memory products mainly to mobile phone manufacturers and PC manufacturers and some networking solution companies. Although Numonyx had a partnership with one of MU's competitors, Hynix, in developing NAND solutions, Numonyx wasn't manufacturing NAND memories at the time. NOR memory market growth had slowed in the past and Numonyx, although enjoyed cash positive, it was still experiencing losses.

The only promise that Numonyx held was in its development of Phase change memory (PCM) and the customer relationships that Numonyx had with many Mobile device manufacturers. Also Phase change memory had been in development for quite some time, and there were doubts about it being launched commercially. So to the average investor there were doubts to whether acquiring Numonyx would add any value to MU.

To analyze this acquisition the assumption is made that for MU, Phase Change Memory (PCM) was the real option that MU had to consider.

4.4.4 NAND vs. NOR

To understand the difference between NAND and NOR memories one has to examine their respective technical and performance characteristics.

NOR - NOR memories have generally being used for PDA's and mobile devices since they can store a certain amount of executable code. So NOR finds itself being used in areas where there is frequent data changes, for NOR has the capability to store and execute the code in place. NOR is fast at reading current data but is slower in erasing and rewriting the data. So for minor applications where not a huge amount of firmware is needed NOR is preferred [44]

NAND – NAND memory has faster erase and write speed but slower speeds when it comes to reading non sequential data. But a very important criteria where NAND scores above NOR memories is that huge amounts of data can be stored easily in NAND memories without significantly affecting its performance. Also NAND proves to be cheaper for high density data storage requirements. Hence NAND is preferred choice of storage when it comes to memory requirements of mp3 players, USB memory sticks, Digital Camcorders, Smart Phones and Tablet computers. Also NAND has exhibited longer life expectancy compared to NOR memories.

Both NOR and NAND memory systems need a supporting data management software to ensure that there is no loss in data.

4.4.5 Changing market conditions in 2010

Market conditions were changing in year 2010 as more and more companies (Memory consumers) were moving towards making smart devices boosting the sales of NAND memory and shrinking NOR sales. The real problem with NOR memory was that, NOR was being constantly replaced by NAND flash memories due to higher data density requirements. The spike in data density requirements was mainly due to the increase in demand for faster write capabilities and increase in media-data stored, mostly in mobile computing devices like Laptops, Tablets and Smart Phones.

4.4.6 Is it wise for MU to acquire Numonyx?

If MU buys Numonyx, it would acquire a company that is selling a product that is already in the late maturity phase of its life cycle. The positive side of the acquisition was that MU was set to gain from mobile phone relationships that Numonyx had and MU had the chance to slowly replacing Numonyx's NOR solutions with better and more advanced NAND solutions that MU already sold. Apart from this, as explained by the then MU CEO, acquisition of Numonyx would make MU bigger than their traditional rival Hynix and give them 19% share of the memory market. 19% share would make MU the second largest market share holder after Samsung who had 29% share of the market. [45]

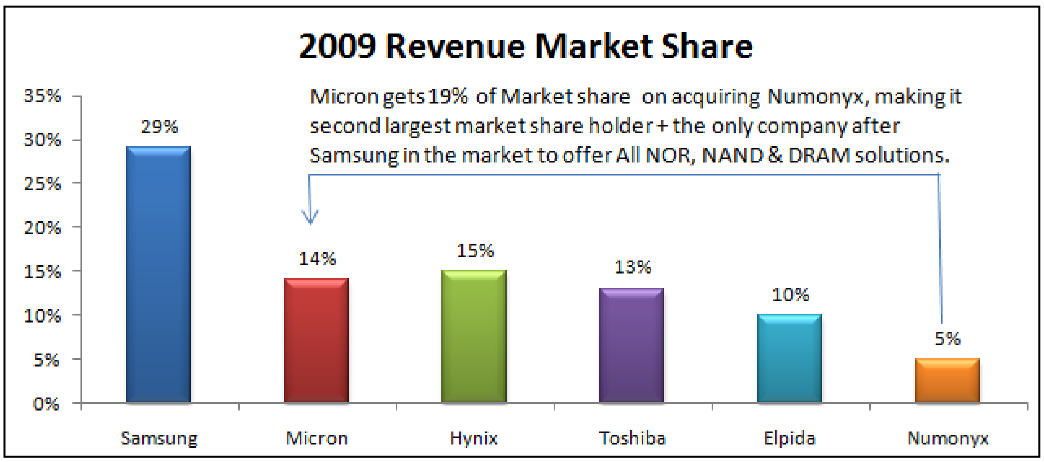


Figure 10 Major players in Memory market (Revenue Market share)

Source: MU Feb 25, 2009 market share. (www.micron.com)

4.4.7 MU's Investor perspective:

During the last 5 years MU had shown a profit in the year 2010 q1 [46]. So from an investor point of view was it reasonable or wise for MU to purchase Numonyx? Especially when MU itself had exited out of the NOR memory market in 2004?

Wells Fargo's analyst David Wong said in a note, "This acquisition has relatively little long term strategic value to Micron but given the opportunity for accretion to cash flow and non-GAAP earnings we view it as being at worst neutral to Micron's share value." [47]

(Market reaction was quite visible as Microns shares fell by 5.4% as soon as MU agreed to acquire Numonyx.) [47]

4. 5 The Strategic Move

The following is a discussion of the strategic advantages that MU would gain if they acquire Numonyx. Here the acquisition is analyzed using both real options analysis and NPV analysis to present a better and clearer picture of the acquisition.

4.5.1 Current and Future market:

Until the acquisition of Numonyx in May 2010, MU had been serving all markets except NOR customers for the Non-volatile memory (NVM) solutions markets. But the greatest opportunity that Micron saw was in the tablet and mobile computing markets. Looking at the earlier trends the wireless eco-systems had seen a surge in demand, and the PC market seemed to be stable, as shown in Figure 16. MU realized that the future need in these segments would demand faster computing, and there would be an increasing demand for higher data storage hardware, as shown in Figure 17.

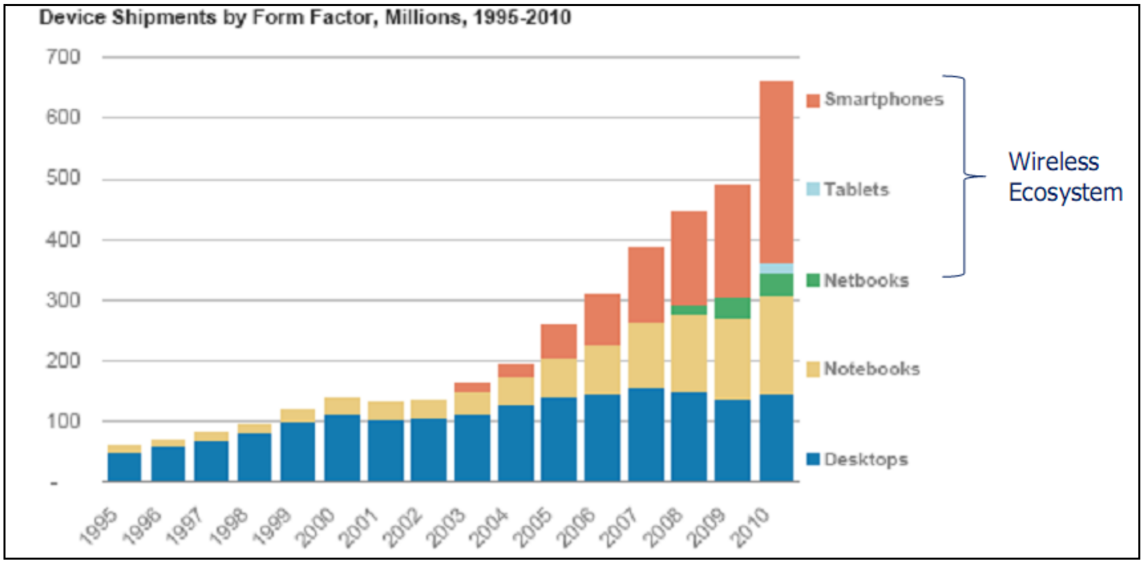


Figure 11 Computing device trends. Source: Morgan Stanley Internet trends, April 2010.

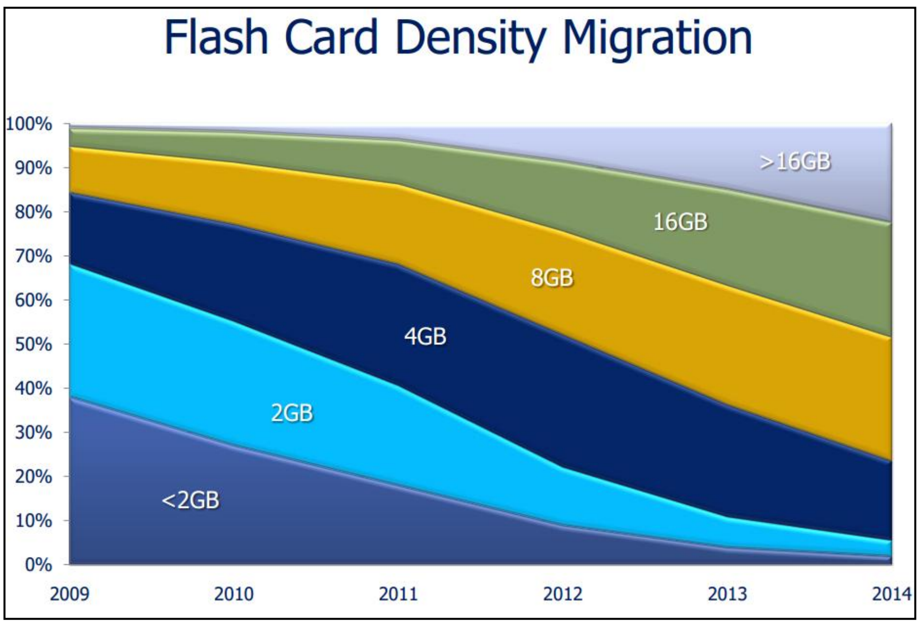


Figure 12 Flash card memory Demand forecasts (Source: iSupply.com Q1 2010)

4.5.2 The Real Option: Phase change memory. (The Intellectual property!!)

A very little known R&D segment of the Numonyx was into Phase change memory (PCM). Numonyx, Samsung, IBM and some other companies have been working on developing Phase change memory technologies from quite some time. Industry insiders and analysts said: “Phase change memory promises to be the next big thing in the industry and would help the market to transition from traditional hard disks to Solid state drives”. [48]

PCM is intended to overcome the short comings of NAND memories. Following are some of the attributes that PCM offered: (Refer to Figure 13 for graphical comparison between PCM and NAND)

- Power consumption: PCM offers higher performance with lower power consumption compared to other memory technologies. Moreover, PCM combines all the best attributes of NOR, NAND and even RAM memories.
- Bit alterability: PCM data can be altered without a separate erase step as required in NOR and NAND memories.
- PCM is non volatile like NOR and NAND memories, i.e. it does not require constant power consumption to retain data.
- PCM offers fast random access times. This enables code to execute directly from memory like in NOR memories without an intermediate copy to RAM as in NAND memories. Also the read latency of PCM is comparable to single-bit-per-cell NOR flash, while the read performance can match DRAM.
- Since there is no separate erase step involved, PCM can achieve write speeds comparable to NAND flash with lower latency. This is compared to NOR memories where the erase step consumes a significant amount of time.

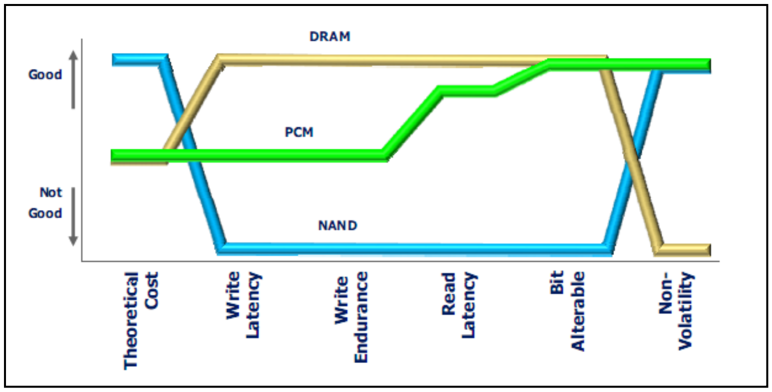


Figure 13 Comparison of PCM vs. NAND and RAM [Error! Bookmark not defined.**].**

- When it comes to write latency and endurance PCM readily bests NAND flash. Although DRAM performs better than PCM, RAM loses out as it is not non-volatile.
- Currently the only place where NAND performs better than PCM is the cost of manufacturing. PCM costs 20% more than the currently available NAND flash technologies, as shown in Table 4. However due to faster read and write capabilities PCM saves costs at the system level.[48] At this writing, NAND proves to be a better overall solution.

Table 4 Theoretical chip cost factors comparison [49].

Silicon Cost Component		SLC PCM	DRAM	SLC NAND
Die Size	Cell Size (F^2)	5.5	6	5
	4G Prod Example	1.0x	1.2x	1.0x
Wafer Complexity	Total Process Mast Count	~35	~34	30
	300 nm cost structure	1.2x	1.2x	1.0x
Theoretical Die Cost Summary		1.2x	1.4x	1.0x

- PCM changes the equation considering reliability. Since NAND has been developed around applications in MP3 players and USB drives there was never a need to increase the write reliability of write times. But when it comes to Enterprise solution applications , wireless solutions (Or solutions that would be needed when cloud networking becomes an everyday reality), it has been observed that NAND memories show errors on stored data as the number of usage cycles increase, as shown in Figure 14. Since PCM bit alterability is not a function of endurance, it is expected that PCM will perform the same after 10 million cycles as it would do after one cycle. .

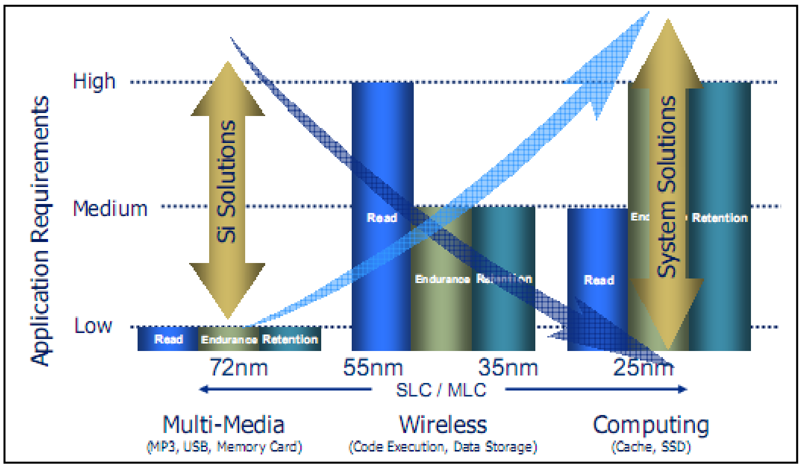


Figure 14 Reliability requirements vs. Litho node size across product segments [49]

- Since the new generation of mobile devices require three basic requirements: instant information, long battery life and great performance for multimedia applications. PCM offers all these due to better read latency performance and lower power consumption. Also the write latency of PCM is almost 100 times faster than NAND flash and almost 10000 times faster than a traditional hard disk. These attributes give PCM the opportunity to replace HDD's (hard disk Drives) with SSD'S.(Solid state disk drives)
- The final factor that favors PCM over NAND flash is endurance scalability, as shown in Figure 17. Until now the scaling that has been achieved is in the 3x nm areas when it comes to NAND flash. Examining Figure 15, NAND flash endurance deteriorates dramatically when its size is reduced to 2x nm whereas PCM holds the promise of being scaled up to 5nm

– 2nm. Also NOR memories seem to get limited when it reaches the 3x nm mark, as shown in Figure 16.

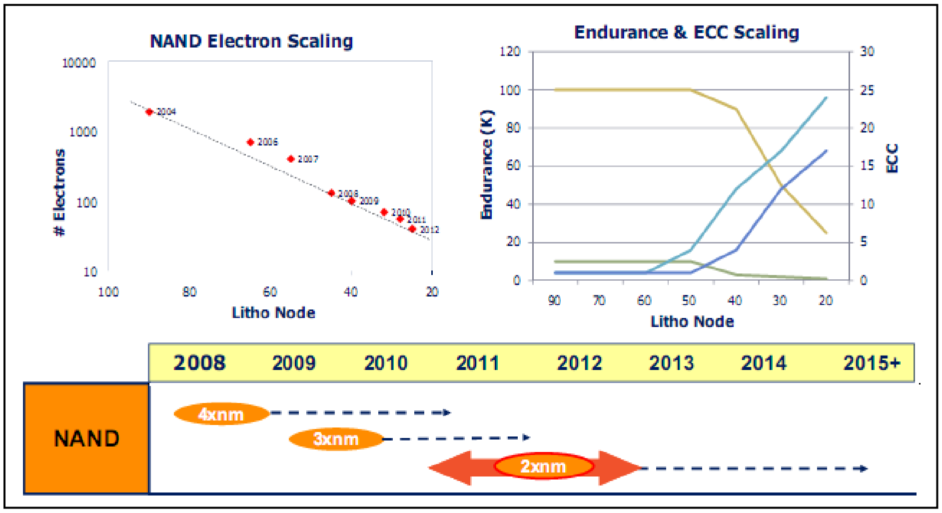


Figure 15 NAND future scaling and limitations [49]

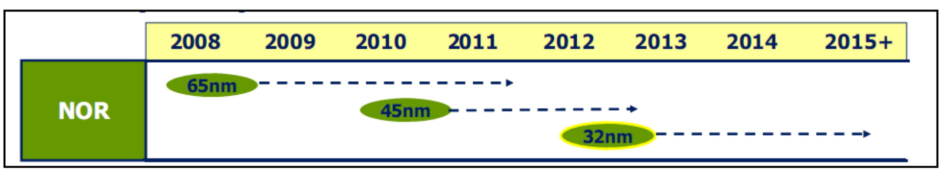


Figure 16 NOR future scaling and Limitations [49]

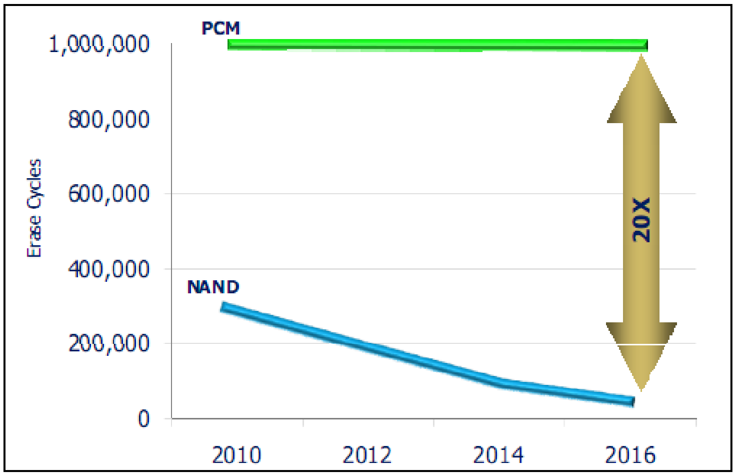


Figure 17 Endurance scalability comparison NAND vs. PCM [49].

The strategic advantage offered MU by acquiring Numonyx was the gain of PCM R&D knowledge that Numonyx had already invested in. So by acquiring Numonyx, MU gained significant knowledge, which they would have to develop themselves, not to mention an investment of their time and money if they would have declined Numonyx offer. So the strategic move was based more on the acquisition of PCM knowledge rather than acquiring a company that manufactured NOR based memory chips. It is likely that this gain could have been one of the reasons that MU recognized a $ 437M gain in the fair value of Numonyx after the acquisition.

4.5.3 The Real Option uncertainty: PCM is still under development

The initial assessment of PCM showed that PCM can perform better than NAND and NOR memories, but still PCM is in development stages and continuing R&D is needed to close the gap to commercial realization. In the current situation, PCM is more expensive than NAND and has not been scaled to the levels of NAND production. [48]

At this time a race between memory companies to develop the first commercially viable PCM chip that could replace HDD’s with SSD’s is underway [58]

An examination of the product life cycle indicates that PCM is in infancy or the early phases when compared to NOR and NAND memory systems, which are in the late majority phases, as shown in Figure 23.

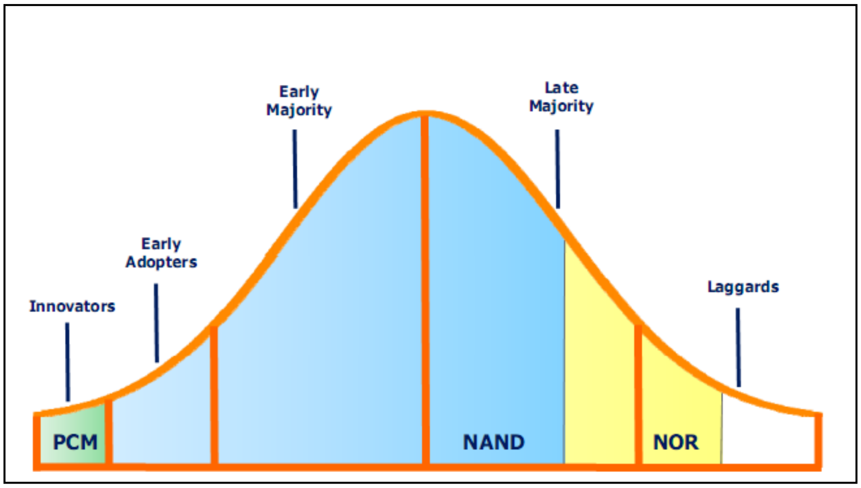


Figure 18 Life cycle comparison between PCM, NOR and NAND [49]

The question for MU.
It is clear that PCM held promise. So the Option for MU is to understand the real value of the Numonyx acquisition and at what value would the acquisition be justifiable.

4.6 Valuation of the Acquisition:

4.6.1 Analyzing the acquisition using the traditional DCF comparison.

Since Numonyx was a private company not much data is available for Numonyx apart from a few references available in interviews with insiders/ reporters, industry analysts and MU executives.

MU's CEO Steve Appleton in an interview has stated that although Numonyx had not been profitable it was still cash generative. [45]

There is no data available as to what cash flows Numonyx did generate. The only clue about Numonyx's cash flow was found in an article on *iSupply.com*, where it was mentioned that Numonyx had reported free cash flows of $42M in Dec 2009. Additionally Numonyx was the top NOR memory supplier in the year 2009, with a market share of 35.4% and had actually increased its revenue market share from the previous quarter by 2% [50].

Realization of fair value by MU after the acquisition.

After the acquisition was complete in Q4 of 2010, MU declared in its financial results that although the Numonyx acquisition was made by paying $1.112 bn, the fair value of the company was realized at $1.549 bn, implying a gain of value in $ 437M. Also MU forecast showed that in future they expected an increase in NOR sales of 8% a year, as shown in Figure 19.

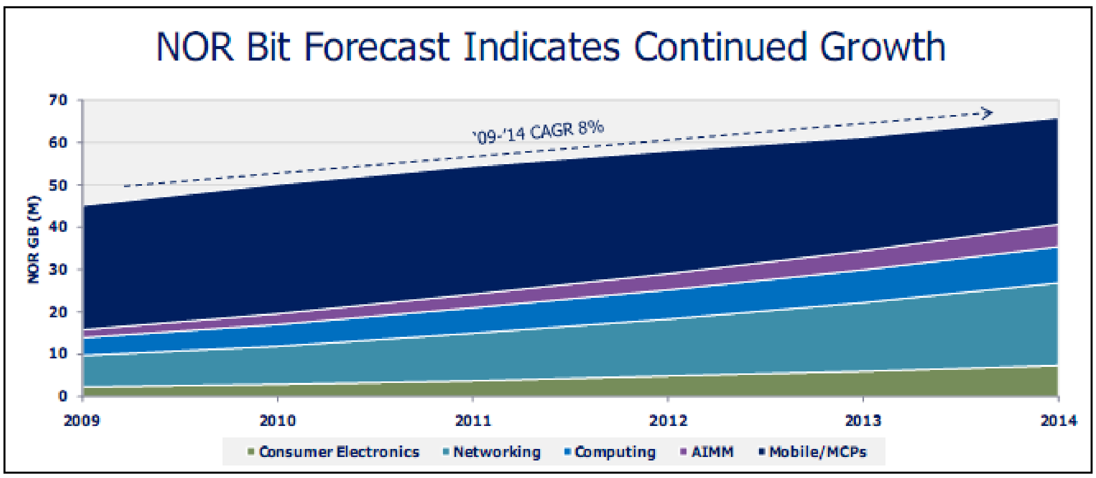


Figure 19 NOR memory growth forecasts Source: MU Q3 Annual Meeting Presentation.

Assumptions considered for the analysis:

For analytical purposes, it was assumed that a limit of 5 years (2014) was set by MU's decision makers for PCM to enter to the commercial market. The reason for this assumption is that industry experts predict that PCM would enter first as a replacement of HDD's by 2014 [51]. Also it would be known by this time if PCM could be produced commercially.

For the purpose of this analysis, a further investment of $ 1bn (i1) would be needed to manufacture these chips. Once this $1bn in invested, the entire PCM operation could be valued at $ 1.7 B. (v1)

If on the other hand PCM cannot be made commercially available to the market, MU can sell Numonyx at no profit but no loss.

Calculating the appropriate discount rate for analysis: After tax WACC (Weighted average cost of capital)

Since any organizations assets are financed either by debt or equity or by a combination of both, it is important to determine how much the company has to spend for each dollar it invests. After tax weighted average cost of capital provides the true discount rate that a company should consider while considering the feasibility of expansionist opportunities and mergers.

Weighted Average cost of capital for MU will be based on their performance in 2009.

The formula for after tax WACC = $(1-T_c)*(D/V)*r_d + (E/V)*r_E$

Where:

T_c = corporate tax rate = -0.99% (Micron reported a loss in the year 2009)

D/V = percentage of financing that is debt = 18.03%

E/V = percentage of financing that is equity = 81.97%

D = market value of the firm's debt = $ 2,581,500,000

E = market value of the firm's equity = $ 11,740,000,000

V = Total capital = E + D = $ 14,321,500,000

r_d = cost of debt = 6.9%

r_E = cost of equity = $r_f + \beta(r_M - r_f)$ = 12.58%

The beta value for MU = β = 1.2

Historical market rate of return for MU = r_M = 11%

Risk free rate based on 30yr bond = r_f = 3.07% ~ 3% (30 year bond rate accessed on 5th may 2012 Google finance http://www.google.com/finance)

So, After tax WACC = $(1-T_c)*(D/V)*r_d + (E/V)*r_E$

After tax WACC = (1-(-0.99%)) x (18.03%) x 6.9% + 81.97% x 12.58% = 11.56% ~ **12%**

So the appropriate discount rate that was chosen to evaluate MU's acquisition of Numonyx was **12%**

Forecasting of Numonyx revenues and profits:

Since Numonyx was a privately held organization, its data was not publically available. So in order to predict future revenue and profits certain assumptions had to be made. An industry analysis of NOR memory done by *Isuppli.com* [50], stated that Numonyx 2009 q4 results had generated a profit of $42 million and revenues of $547 million [45]. Also MU had, forecasted that the compounded annual growth rate, for the NOR segment would be roughly 8% in the forth coming years as shown in Figure 19. Thus for calculation purposes it was determined that Numonyx revenue is assumed to be $550 million (unchanging for the years to come) and the profits would grow for the next 5 years at 8% annually.

Traditional Discounted Cash flow analysis:

Initial investment for acquisition: $1112M.

Realized fair value: $1549M.

Gain from realization: $437M.

Table 5 Discounted cash flow analysis: Numonyx Acquisition

Years	Revenue	Cost	Profit	NPV (R = 12%)	i1	NPV i1	v1	NPV v1
2010	$550.00	$508.00	$42.00	$37.50				
2011	$550.00	$504.64	$45.36	$36.16				
2012	$550.00	$501.01	$48.99	$34.87				
2013	$550.00	$497.09	$52.91	$33.62				
2014	$550.00	$492.86	$57.14	$32.42	$1,000.00	**$567.43**	$1700	**$964.63**

All values in millions

So the valuation of Numonyx would be:

Valuation = - Initial investment + gain from fair value realization + Net present values(NPV) of all cash flows up till year 2014 - Net present value of additional investment of $ 1bn + Net present value of the value gained by additional investment (See Table 5).

= -$103.224 million dollars.

Examination of the Numonyx acquisition using the traditional NPV would have proven a negative net value and the decision would have been made to not buy Numonyx.

But the problem with this analysis is that the future investment of $1bn is considered from the onset of the acquisition, while it actuality this expenditure represents an option to decide whether to invest or not to invest, at a future time.

4.6.2 Accounting for managerial flexibility

It should always remain MU’s choice as to whether to exercise the right to expand or not or to abandon any project in its entirety at any future time. So the expansion opportunity is basically a real option that MU can exercise or decline to make in the future.

In the discounted cash flow example, managerial flexibility was not taken into account and hence it is accurate to say that the valuation did not really represent the true value of the proposed acquisition.

4.6.3 Analyzing Using a decision tree incorporating Black and Scholes option pricing formula.

Choices:

The decision choices for MU can be broken down into three categories:

Option 1) Decline to invest in Numonyx

Option 2) Defer investment for a year and buy Numonyx if it is still available after a year. (No license or lease needed to purchase one year deferment)

Option 3) Invest now in Numonyx and decide after 3 years to further invest in PCM or to sell off Numonyx for no profit and but no loss, (depending upon developments in PCM commercial viability)

Calculation of Pay offs for each decision choice:

Option 1) Decline to invest: Since there is no investment done, MU stands to lose nothing but just the opportunity cost. So the pay off here would be $0.

Option 2) Defer investment for a year:

Now this option generally is chosen to get a better understanding of the market dynamics to make a better informed decision. And by then there is still a decision choice whether one should buy or invest or decline.

Branching of the option can be designed as below with each bullet step representing the path of the decision tree.

Option2: Defer investment for year.

- Numonyx Offer still available.
    - Invest in Numonyx

- Decide to go ahead with PCM if PCM becomes a commercially viable option
    - Decline to make further PCM investment if PCM is not a commercially viable option and sell off Numonyx for no profit but no loss.
- Decline to invest in Numonyx

Identifying the correct probabilities for chance points: *Current situation analysis (2010) (Pre-Numonyx acquisition)*

The situation concerning Numonyx is that, since it is a market leader in NOR technologies there would be other companies pursuing the acquisition thus MU risks losing the opportunity to acquire it to its competitors like Hynix and Samsung who were also closely monitoring the market as well. Secondly even in the NOR segment, companies like Macronix or Hynix could be eyeing Numonyx if it ever come up for sale. One can assume that there is a 50% chance that Numonyx might be acquired by some other company.

If MU acquires Numonyx after a year one can assume that the cost of acquisition may go up by 10%, (due to inflation and more information available in the marketplace about PCM raising the value of Numonyx, also CAGR (Compound Annual Growth Rate) for NOR is expected to be 8% a year as estimated by MU's analysts.) If that happens Micron would pay an increased price of $1.2232 bn for acquiring Numonyx. This would offset the final pay off by a negative $ 172.29M as shown in the (traditional NPV) calculations in Table 6.

Initial investment for acquisition: $ 1223.2 million.

Realized fair value: $1549 million. (It can be argued that the realized fair value might increase or decrease during the decision delay period, but due to lack of data, it was assumed that realized fair value would remain the same)

Gain from realization: $325.80 million.

Table 6 Cash flow Analysis using Real Options approach: Numonyx Acquisition Defer investment for a year.

Years	Revenue	Cost	Profit	NPV (R = 12%)	i1	NPV i1	v1	NPV v1
2011	$550.00	$504.64	$45.36	$40.50				
2012	$550.00	$501.01	$48.99	$39.05				
2013	$550.00	$497.09	$52.91	$37.66				
2014	$550.00	$492.86	$57.14	$36.31	$1,000.00	$635.52	$1,700.00	**$1,080.38**

All values in millions

To calculate the value of the future investment as a Real Option, Black and Scholes option pricing formula was needed and the following values are established.

Strike Price: $1080.38M

Exercise price: $ 1000M

Time: 4 years = 1440 days

Risk free rate: r_f *= 3.07% ~ 3% (30 year bond rate accessed on 5th may 2012 Google finance* http://www.google.com/finance)

Volatility = 0.64 (0.64 is the volatility of the stock price of MU, which is a proxy for their volatility of their cash flow.)

Putting these values in excel following equation (E1), the option value obtained is $571.58M, as shown in Table 7.

Table 7 Option calculator (MS Excel)

Black and Scholes model Option 2 Defer now and invest in 2011		
	Option values	Defer for a year
Current Price	S	$1,080.38
Exercise price	X	$1,000.00
Volatility	σ	64.00%
Risk free rate	r_f	3.00%
Time (years)	T	4
Div yield	q	0.00%
	d1	0.794
	d2	-0.486
Option value:	**C**	**$571.58**

The call option price = $ 571.58M

So the total valuation of Numonyx becomes:

Valuation = NPV Cash inflows (Current operations only) + gain from value realization + Price of the option to expand to PCM – NPV of Initial investment.

Valuation (in $ millions) = $153.53 + $325.80 + $571.58 – 1223.3 = $ -172.29 million.

The calculation indicates that this choice/option would result in a loss if Numonyx is bought after a year.

The other choice in the different option would be to decline the offer to invest in Numonyx resulting in $0 gain or loss. Not accounting for future opportunity cost.

Option 3 to invest now:

Now if this option is selected, MU would acquire Numonyx in the year 2010, and would wait until 2014 when the information about the viability of PCM would be more clearly available, to make a final decision to further invest in PCM or decline to make the investment. From the data available as of today there is a 70% chance that PCM would become a commercially viable option and a 30%

chance that PCM would not be a commercially viable option. But again the engineering managers at MU would retain decision flexibility and with more information available to them in the year 2014 make a better informed decision.

Branching of the option can be designed as below with each bullet step representing the path of the decision tree.

Option 3: Invest now in Numonyx in 2010

- Further invest in PCM if it becomes commercially viable
- If PCM is not commercially viable sell of Numonyx for no profit but no loss

Payoffs of each of these options are calculated below.

Initial investment for acquisition: $1112 million.

Realized fair value: $1549 million.

Gain from realization: $437 million.

Table 8 Cash flow Analysis using Real Options approach: Numonyx Acquisition (Invest now option)

Years	Revenue	Cost	Profit	NPV (R = 12%)	i1	NPV i1	v1	NPV V1
2010	$550.00	$508.00	$42.00	$37.50				
2011	$550.00	$504.64	$45.36	$36.16				
2012	$550.00	$501.01	$48.99	$34.87				
2013	$550.00	$497.09	$52.91	$33.62				
2014	$550.00	$492.86	$57.14	$32.42	$1,000.00	$567.43	$1,700	$964.63

All values in millions

The option to invest in the future, using the Black and Scholes option formula, can also be performed.

Strike Price: $964.63 million

Exercise price: $1000 million

Time: 5 years = 1800 days

Risk free rate: r_f = *3.07% ~ 3% (30 year bond rate accessed on 5th may 2012 Google finance* http://www.google.com/finance)

Volatility = 0.64 (0.64 is the volatility of the stock price of MU, which is a proxy for their volatility of their cash flow.)

Putting these values in Excel following equation (E1), the option value obtained is $533.05 million dollars, as shown in Table 9.

Table 9 Option calculator (MS Excel)

Black and Scholes model Option 3 invest now		
	Option values	Invest Now
Current Price	S	$964.63
Exercise price	X	$1,000.00
Volatility	σ	64.00%
Risk free rate	r_f	3.00%
Time	T	5
Div yield		0.00%
	d1	0.795
	d2	-0.636
Option Value	**C**	**$533.05**

The call option value = $ $533.05 million

So now the calculated the valuation of this option can be performed.

Valuation = NPV Cash inflows (Current operations only) + gain from value realization + Price of the option to expand to PCM - Initial investment.

Valuation = $174.58 + $437 + $533.05 - $1112 = $32.63 million dollars.

The other choice, to decline the future investment if PCM is not commercially available, would be to sell off Numonyx then for no profit but no loss resulting in a payoff of $0.

The decision Tree:

We can see that the option selected is Option 3: The invest now option as it proves to be the most profitable option.

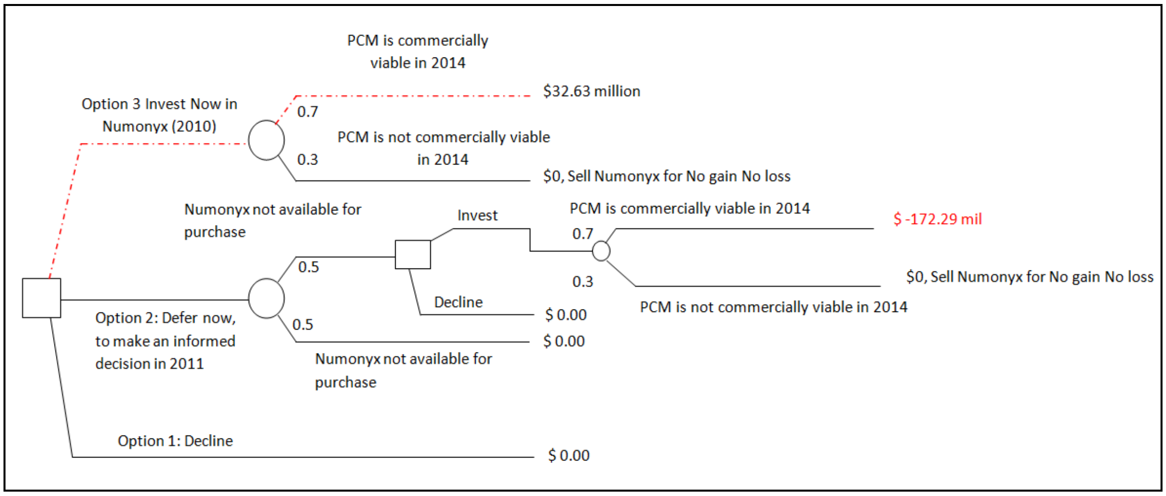


Figure 20 Decision tree for Numonyx acquisition.

Following the above analyses one can say that if MU's decision makers had carried out the analysis just using the traditional discounted cash flow valuation method they would have declined to make the Numonyx acquisition. But carrying out a real options analysis which incorporated managerial flexibility to some extent, resulted in a better estimate of the true value of the acquisition of Numonyx and economically supports the decision that was actually made.

4.7 Sensitivity Analysis:

During the conception of the decision tree, there were many assumptions made. So to gain a better understand of the impact of these variables on the outcome it becomes necessary to carry out a sensitivity analysis. The reason of doing sensitivity analysis is to better understand the outcome of the decision and also to understand what changes in outcome can lead to changes in the decision made.

Thus sensitivity analysis can present a clearer picture to the engineering manager, which can help the engineering manager to monitor the business process more accurately.

4.7.1 Sensitivity analysis on the assumed probabilities representing internal risk in the decision tree model.

In the decision tree analysis, the possibility of PCM becoming a commercially viable product depends on internal capabilities of MU as well as the acquired capabilities of Numonyx. The probabilities thus assumed if the state of nature turns out to be good was 0.7 and Bad 0.3 as shown (Highlighted) in the decision tree shown in Figure 21.

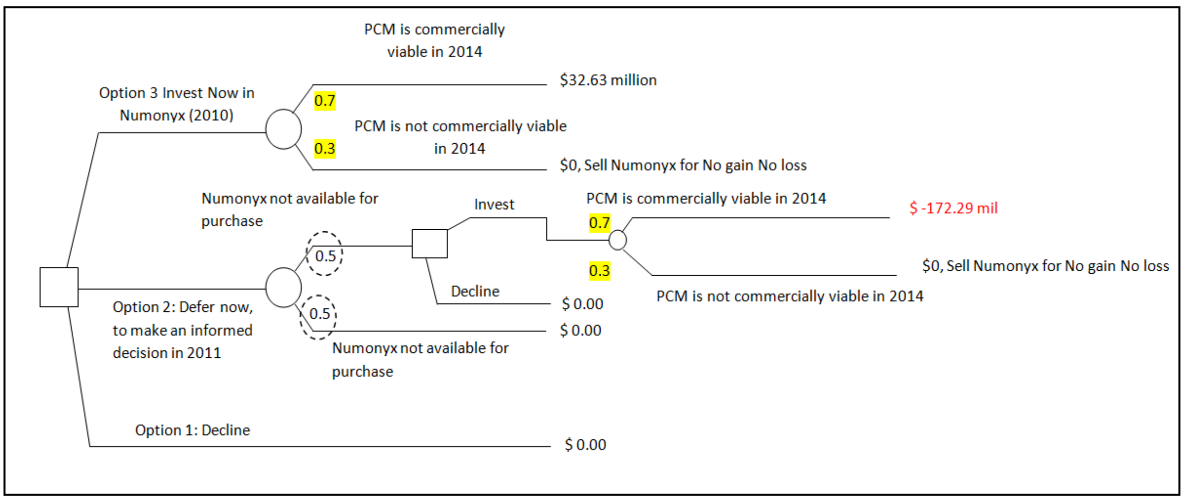


Figure 21 Decision Tree: Highlighted Internal Risk probabilities

If everything else remains constant, one can run a sensitivity analysis these probabilities in order to understand their impact on the decision that should be made. Table 10 contains the values of the outcomes or expected monetary value (EMV) when subjected to changes in the probabilities of the "Good" and "Bad" states of nature.

Table 10 One–way Sensitivity analysis: Changing Internal Risk Probabilities vs. EMV outcomes

	States of nature (Internal Risk probabilities)		Outcomes (millions)		
	Good	Bad {1 - Good}	**EMV Option 3**	**EMV Option .2**	**EMV Option 1**
Probability	**0.1**	0.9	**$3.26**	**$0.00**	**$0.00**
	0.2	0.8	**$6.53**	**$0.00**	**$0.00**
	0.3	0.7	**$9.79**	**$0.00**	**$0.00**
	0.4	0.6	**$13.05**	**$0.00**	**$0.00**
	0.5	0.5	**$16.31**	**$0.00**	**$0.00**
	0.6	0.4	**$19.58**	**$0.00**	**$0.00**
	0.7	0.3	**$22.84**	**$0.00**	**$0.00**
	0.8	0.2	**$26.10**	**$0.00**	**$0.00**
	0.9	0.1	**$29.36**	**$0.00**	**$0.00**
	1	0	**$32.63**	**$0.00**	**$0.00**

A Graph can be plotted using the data in as shown in Table 10, as shown in Figure 29. On the varying probabilities of the Good state of nature and the EMV values of the three options, one can clearly see that Option 3 dominates both Option 2 and Option 1 regardless of the viability of commercially available PCM.

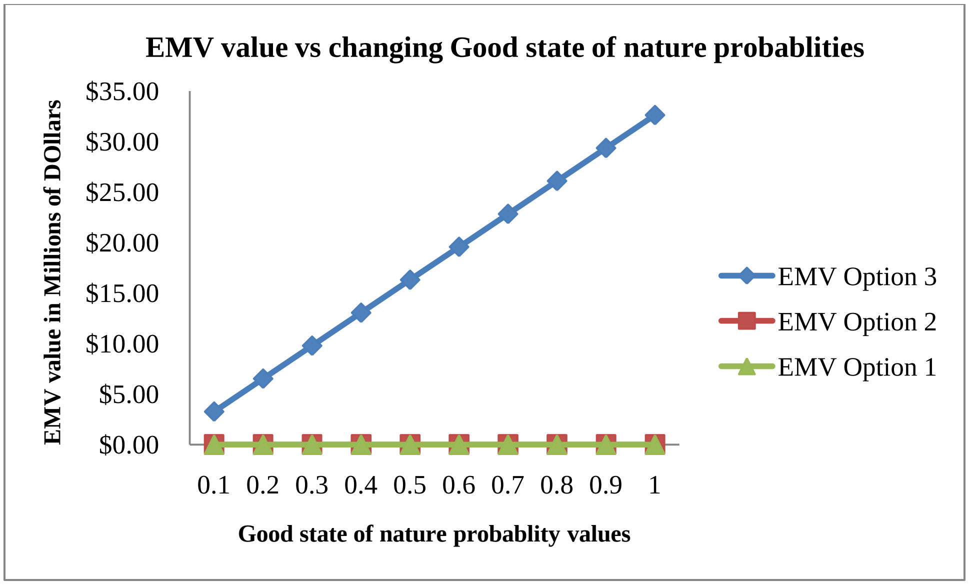


Figure 22 EMV graph: Changing Internal risk Probabilities

From this analysis, change in internal risk probabilities between the range of 0.1 to 1, have no effect on the decision, as Option 3 dominates Option2 and Option 1.

4.7.2 Sensitivity analysis on the probabilities representing the risk of losing the acquisition deal due to delay caused by defer option 2.

Re-examination of Option 2 in the decision tree, Figure 21, there is a 0.5 (circled in dashed lines) chance of Numonyx not being available for the purchase; here keeping everything else constant the maximum value would $0. So change in these probabilities would also not impact the selection of Option 3 as the optimum decision outcome.

4.7.3. Two-way sensitivity analysis: Option 3 EMV outcomes on varying the volatility and Initial investment needed to acquire Numonyx.

In calculating the true EMV for option 3, two assumptions that were used were the volatility which was considered to be 64% and the initial investment amount of $1.112 B. To analyze the impact of these two variables on the EMV of Option 3 a two-way sensitivity analysis was carried out and the results thus obtained are shown in Table 11 and also shown in Figure 23.

Table 11 Two- way sensitivity analysis: volatility vs. initial investment to acquire Numonyx (Option 3 EMV's)

σ	Option 3 EMV	Initial Investment Option 3 (Invest Now) (Millions)							
		$700.00	**$800.00**	**$900.00**	**$1,000.00**	**$1,100.00**	**$1,200.00**	**$1,300.00**	**$1,400.00**
Volatility	**10.00%**	$467.06	$267.06	$67.06	($132.94)	($332.94)	($532.94)	($732.94)	($932.94)
	20.00%	$542.14	$342.14	$142.14	($57.86)	($257.86)	($457.86)	($657.86)	($857.86)
	30.00%	$618.60	$418.60	$218.60	$18.60	($181.40)	($381.40)	($581.40)	($781.40)
	40.00%	$693.05	$493.05	$293.05	$93.05	($106.95)	($306.95)	($506.95)	($706.95)
	50.00%	$764.18	$564.18	$364.18	$164.18	($35.82)	($235.82)	($435.82)	($635.82)
	60.00%	$831.14	$631.14	$431.14	$231.14	$31.14	($168.86)	($368.86)	($568.86)
	70.00%	$893.35	$693.35	$493.35	$293.35	$93.35	($106.65)	($306.65)	($506.65)
	80.00%	$950.40	$750.40	$550.40	$350.40	$150.40	($49.60)	($249.60)	($449.60)
	90.00%	$1,002.05	$802.05	$602.05	$402.05	$202.05	$2.05	($197.95)	($397.95)
	100.00%	$1,048.23	$848.23	$648.23	$448.23	$248.23	$48.23	($151.77)	($351.77)

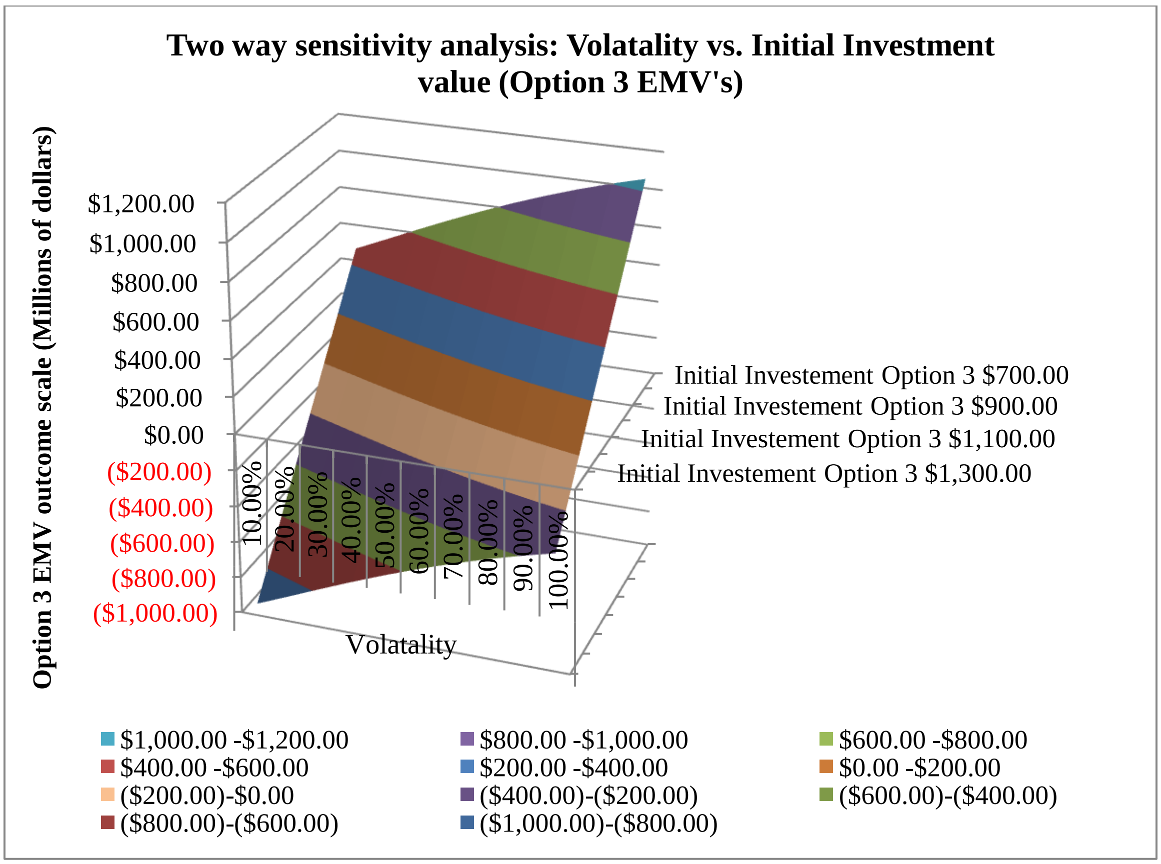


Figure 23 Two- way sensitivity analysis: volatility vs. initial investment to acquire Numonyx (Option 3 EMV's)

In the graph (Figure 23), the x axis is represented by volatility ranging from 10% to 100%, the y axis is represented by initial investment values decreasing from $1.4 B. to $0.7 B. and the z axis represents the EMV values of Option 3.

The different color bands represent the different ranges with respect to value ranges shown in the legends of the graph (Figure 23).

As expected, the maximum value is where the volatility is maximum and the initial investment is lowest, and the breakeven point the initial investment range of $1.3 B. to $1.2 B. and volatility being as high as 90% - 100%.

4.7.4 Two-way sensitivity analysis: Option 2 EMV outcomes on varying the volatility and Initial investment needed to acquire Numonyx.

In the modeling of the second branch of the decision tree, one of the assumptions made, regarded the initial investment as a price increase of 10% with no additional increase in realized value was modeled. It was assumed that if Numonyx was available for acquisition after a year (in 2011), its acquisition price would increase by 10% to $1.22320 B. and at a volatility of 64%.

To analyze the impact of volatility and this price on the EMV of Option2 a two sensitivity analysis was carried out and the results thus obtained are shown in Table 12 and also shown in the graph (See Figure 24).

Table 12 Two- way sensitivity analysis: volatility vs. initial investment to acquire Numonyx (Option 2 EMV's)

σ	Option 2 EMV	Initial Investment Option 2 (Defer now option) (Millions)							
		$700.00	$800.00	$900.00	$1,000.00	$1,100.00	$1,200.00	$1,300.00	$1,400.00
Volatility	**10.00%**	$512.67	$312.67	$112.67	($87.33)	($287.33)	($487.33)	($687.33)	($887.33)
	20.00%	$573.46	$373.46	$173.46	($26.54)	($226.54)	($426.54)	($626.54)	($826.54)
	30.00%	$643.24	$443.24	$243.24	$43.24	($156.76)	($356.76)	($556.76)	($756.76)
	40.00%	$713.75	$513.75	$313.75	$113.75	($86.25)	($286.25)	($486.25)	($686.25)
	50.00%	$782.61	$582.61	$382.61	$182.61	($17.39)	($217.39)	($417.39)	($617.39)
	60.00%	$848.65	$648.65	$448.65	$248.65	$48.65	($151.35)	($351.35)	($551.35)
	70.00%	$911.14	$711.14	$511.14	$311.14	$111.14	($88.86)	($288.86)	($488.86)
	80.00%	$969.57	$769.57	$569.57	$369.57	$169.57	($30.43)	($230.43)	($430.43)
	90.00%	$1,023.62	$823.62	$623.62	$423.62	$223.62	$23.62	($176.38)	($376.38)
	100.00%	$1,073.09	$873.09	$673.09	$473.09	$273.09	$73.09	($126.91)	($326.91)

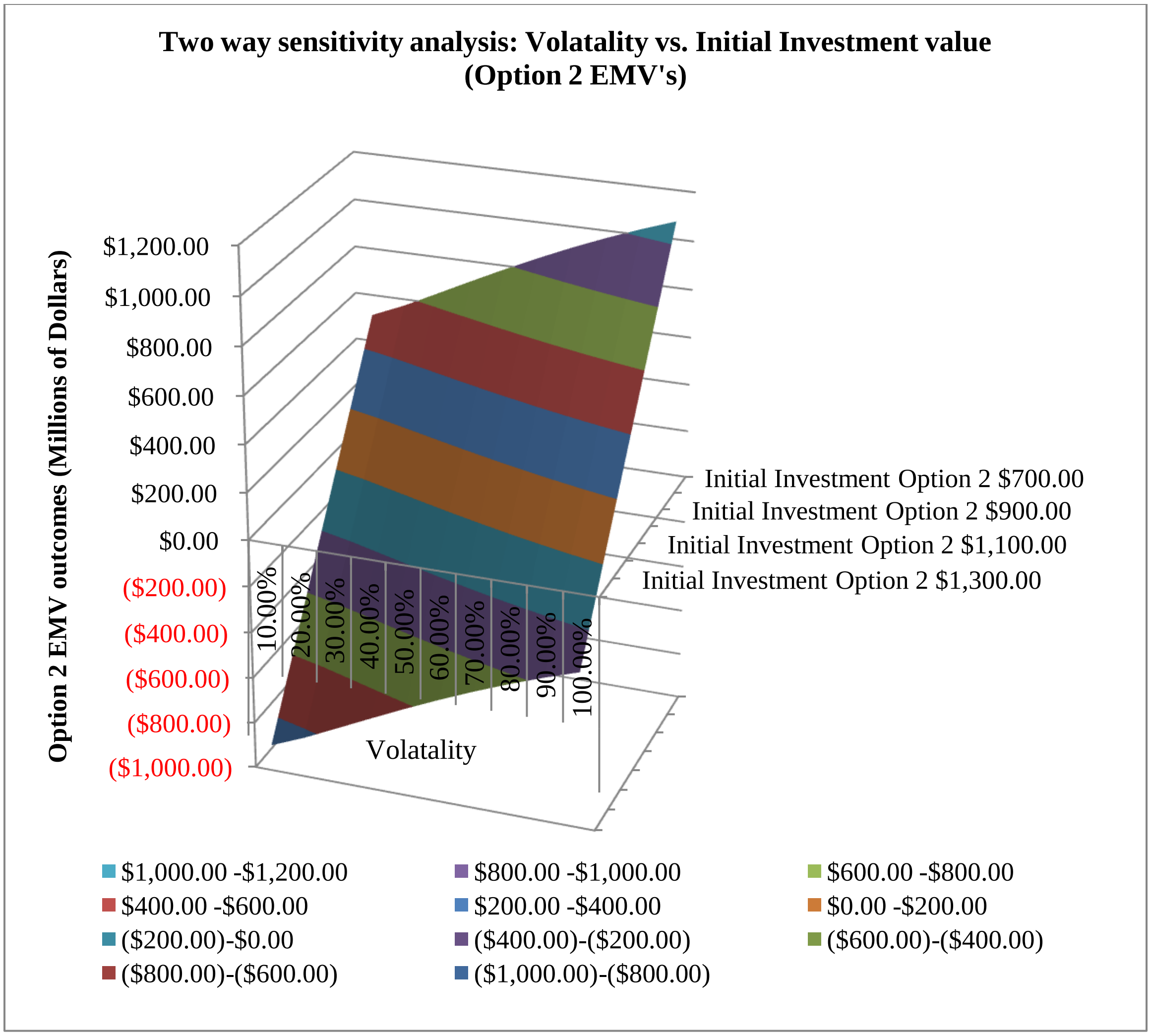


Figure 24 Two- way sensitivity analysis: volatility vs. initial investment to acquire Numonyx (Option 2 EMV's)

In the graph (Figure 31), the x axis is represented by volatility ranging from 10% to 100%, the y axis is represented by initial investment values ranging from $1400 Million and $700 million and the z axis represents the EMV values of Option 3.

The different color bands represent the different ranges of EMV shown in the legends of the graph (Figure 24). As expected, the maximum value is where the volatility is maximum and the initial investment amount is lowest, and the breakeven point the initial investment range of $1.3 B. to $1.2 B. and volatility being as high as 90% - 100%.

4.7.5 Two way sensitivity analysis comparison: Volatility vs. Initial investment value considering Option2 EMV's (*section 4.7.4*) greater than Option 3 EMV (*section 4.7.3*) along with Option 1 EMV's of $0

In order to gauge at what volatility and initial investment values Option 2 EMV's yields a higher value than Option 1 and Option 3, a two-way sensitivity analysis was carried out between volatility, ranging from 10% to 100% and Initial investment values ranging from $700 million to $1.4 billion.

The result of this sensitivity analysis is shown in the Table 13. Also the graph shown in Figure 25 shows the value ranges where Option 2 Dominates over Option 1 and Option 3.

Table 13 Option 2 EMV's greater than Option 3 EMV of $32.63 mil. And Option 1 EMV of $0

Option 2 EMV's greater than Option 3 EMV of $32.63 mil. And Option 1 EMV of $0		Initial Investment values (Millions)							
		$700.00	$800.00	$900.00	$1,000.00	$1,100.00	$1,200.00	$1,300.00	$1,400.00
Volatility	10.00%	$512.67	$312.67	$112.67	$0.00	$0.00	$0.00	$0.00	$0.00
	20.00%	$573.46	$373.46	$173.46	$0.00	$0.00	$0.00	$0.00	$0.00
	30.00%	$643.24	$443.24	$243.24	$43.24	$0.00	$0.00	$0.00	$0.00
	40.00%	$713.75	$513.75	$313.75	$113.75	$0.00	$0.00	$0.00	$0.00
	50.00%	$782.61	$582.61	$382.61	$182.61	$0.00	$0.00	$0.00	$0.00
	60.00%	$848.65	$648.65	$448.65	$248.65	$48.65	$0.00	$0.00	$0.00
	70.00%	$911.14	$711.14	$511.14	$311.14	$111.14	$0.00	$0.00	$0.00
	80.00%	$969.57	$769.57	$569.57	$369.57	$169.57	$0.00	$0.00	$0.00
	90.00%	$1,023.62	$823.62	$623.62	$423.62	$223.62	$0.00	$0.00	$0.00
	100.00%	$1,073.09	$873.09	$673.09	$473.09	$273.09	$73.09	$0.00	$0.00

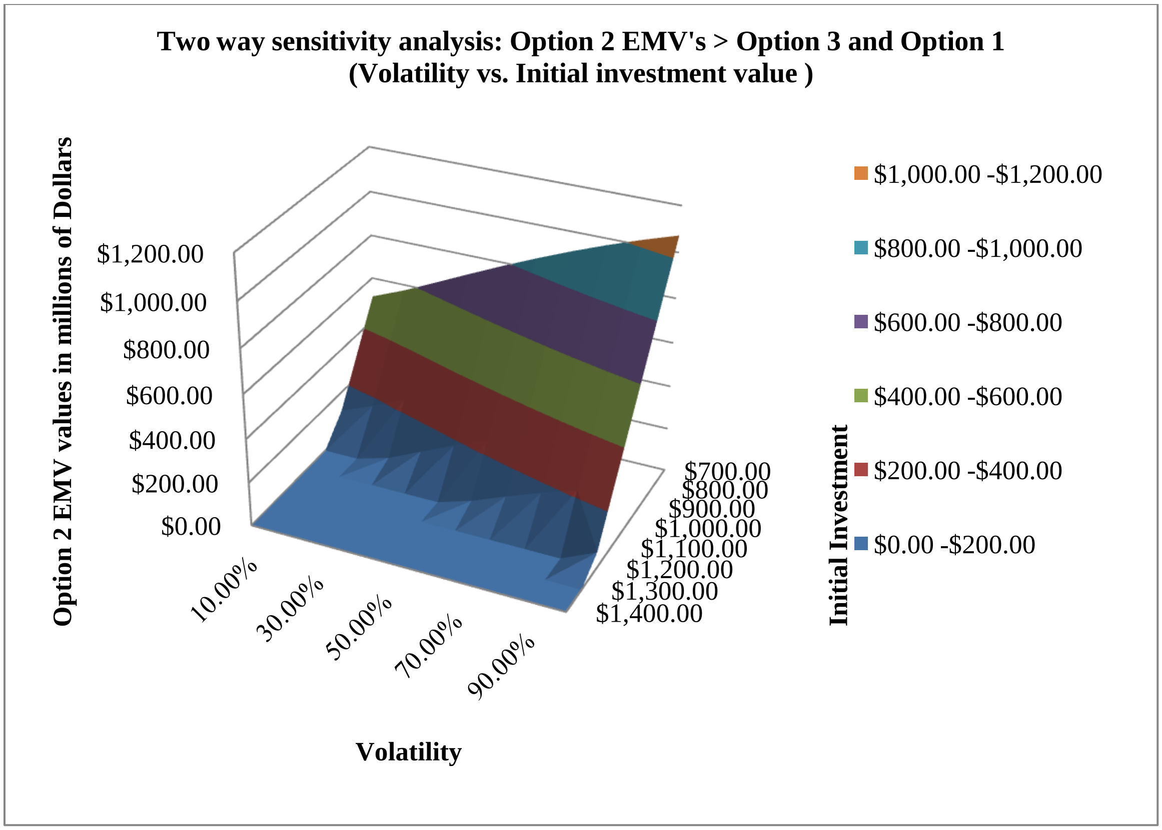


Figure 25 Two way sensitivity analysis: Option 2 EMV's > Option 3 and Option 1 (Volatility vs. Initial investment value)

Looking at Table 13 it is clear that at initial investment amounts falling below $0.7 B. to $0.9 B. Option2 EMV yields are much higher than Option 1 and Option 3 outcome at all volatility levels, and after that between $1 B. and $1.2 B. the EMV yields drop and completely diminish at an initial investment of $1.3 B. This can also be seen in the Graph shown in Figure 25, that after initial investment values of $ 1.1 B. there is a steep fall and the EMV is $0 at all volatility values. So one can again deduce that at lower initial investment values and higher volatility values Option2 performs better than both option 1 and option 3.

4.7.6 Two way sensitivity analysis for Option 2: Varying Percent increase in initial value vs. volatility

The assumptions that were made while modeling Option 2, was that the initial investment price for acquiring Numonyx would increase by 10% and the volatility for the underlying investment would be

64%. In order to test the impact of these values on the EMV outcomes was tested using a two sensitivity analysis. Table 14 represents the results thus obtained.

From the Table 14, one can observe that even at 1% increase in acquisition value of Numonyx and volatility at 64% the valuation of Option 2 is $27.87M which is less than the value obtained by the Option 3 (invest now) ($32.63M).

The risk free rate used was 3%. So the value of the acquisition could have increased by 3% at least, but even with a lower value of 1% increase Options 2 still would not be selected over Option 3 which yields a greater return.

In order to understand, at what values of percent increase in initial value and volatility Option 2 would yield a higher value than Option 3's a Binary table was created, the results of which are shown in Table 15. The area (pointed with and arrow) in the graph shown in Figure 26 plots the test variable ranges where option 2 has an EMV higher than option 3 (and Option 1).

Table 14 Two-way sensitivity analysis for Option 2: Varying Percent increase in initial value vs. volatility

σ	Option 2 EMV	Percent increase in the acquisition value of Numonyx (1 to 15%) (Millions)														
		1.00%	2.00%	3.00%	4.00%	5.00%	6.00%	7.00%	8.00%	9.00%	10.00%	11.00%	12.00%	13.00%	14.00%	15.00%
Volatility	10%	-$333.57	-$355.81	-$378.05	-$400.29	-$422.53	-$444.77	-$467.01	-$489.25	-$511.49	-$533.73	-$555.97	-$578.21	-$600.45	-$622.69	-$644.93
	20%	-$272.78	-$295.02	-$317.26	-$339.50	-$361.74	-$383.98	-$406.22	-$428.46	-$450.70	-$472.94	-$495.18	-$517.42	-$539.66	-$561.90	-$584.14
	30%	-$203.00	-$225.24	-$247.48	-$269.72	-$291.96	-$314.20	-$336.44	-$358.68	-$380.92	-$403.16	-$425.40	-$447.64	-$469.88	-$492.12	-$514.36
	40%	-$132.49	-$154.73	-$176.97	-$199.21	-$221.45	-$243.69	-$265.93	-$288.17	-$310.41	-$332.65	-$354.89	-$377.13	-$399.37	-$421.61	-$443.85
	50%	-$63.63	-$85.87	-$108.11	-$130.35	-$152.59	-$174.83	-$197.07	-$219.31	-$241.55	-$263.79	-$286.03	-$308.27	-$330.51	-$352.75	-$374.99
	60%	$2.41	-$19.83	-$42.07	-$64.31	-$86.55	-$108.79	-$131.03	-$153.27	-$175.51	-$197.75	-$219.99	-$242.23	-$264.47	-$286.71	-$308.95
	64%	$27.87	$5.63	-$16.61	-$38.85	-$61.09	-$83.33	-$105.57	-$127.81	-$150.05	-$172.29	-$194.53	-$216.77	-$239.01	-$261.25	-$283.49
	70%	$64.90	$42.66	$20.42	-$1.82	-$24.06	-$46.30	-$68.54	-$90.78	-$113.02	-$135.26	-$157.50	-$179.74	-$201.98	-$224.22	-$246.46
	80%	$123.33	$101.09	$78.85	$56.61	$34.37	$12.13	-$10.11	-$32.35	-$54.59	-$76.83	-$99.07	-$121.31	-$143.55	-$165.79	-$188.03
	90%	$177.38	$155.14	$132.90	$110.66	$88.42	$66.18	$43.94	$21.70	-$0.54	-$22.78	-$45.02	-$67.26	-$89.50	-$111.74	-$133.98
	100%	$226.85	$204.61	$182.37	$160.13	$137.89	$115.65	$93.41	$71.17	$48.93	$26.69	$4.45	-$17.79	-$40.03	-$62.27	-$84.51

Table 15 Option 2 Binary Table (Percent Increase in acquisition value vs. volatility: 1 where Option2 EMV is greater than Option 3 EMV value of $32.63 mil.)

σ	Option 2 Binary	Percent increase in the acquisition value of Numonyx (1 to 15%)										
		1.00%	2.00%	3.00%	4.00%	5.00%	6.00%	7.00%	8.00%	9.00%	10.00%	11.00%
Volatility 0 - 100%	10.00%	0	0	0	0	0	0	0	0	0	0	0
	20.00%	0	0	0	0	0	0	0	0	0	0	0
	30.00%	0	0	0	0	0	0	0	0	0	0	0
	40.00%	0	0	0	0	0	0	0	0	0	0	0
	50.00%	0	0	0	0	0	0	0	0	0	0	0
	60.00%	0	0	0	0	0	0	0	0	0	0	0
	64.00%	0	0	0	0	0	0	0	0	0	0	0
	70.00%	1	1	0	0	0	0	0	0	0	0	0
	80.00%	1	1	1	1	1	0	0	0	0	0	0
	90.00%	1	1	1	1	1	1	1	0	0	0	0
	100.00%	1	1	1	1	1	1	1	1	1	0	0

Binary values where one (1) represents Option 2's EMV for the corresponding percent increase in initial investment value and the corresponding volatility value, is higher than Option 3 EMV while a zero (0) represents all the values where Option2 EMV for the corresponding volatility and percent increase in initial investment value is lower than Option 3's EMV.

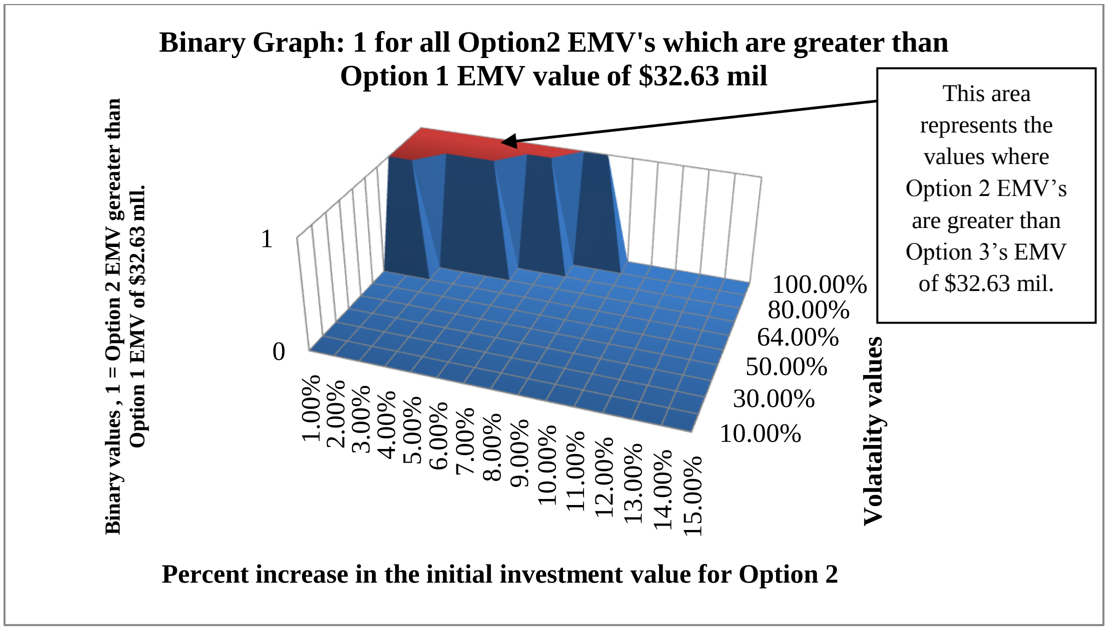


Figure 26 Binary Graph where Option 2 EMV yields higher than Option 3 EMV

4.7.7 Two-way Sensitivity analysis between volatility and initial investment values to determine where declining the acquisition offer (Selecting Option1) would prove a better choice compared to Option 2 and Option3

Since selection of Option 1, is optimal when Option 2 and Option3 EMV's are negative a Two-way sensitivity table of volatility vs. initial investment values for both Option 3 and Option 2 were compared, namely Table 11 and Table 12 were constructed.

The condition for creation of such a binary table was to select each corresponding volatility and initial investment values, where the EMV's of Option 2 and Option 3 is less than zero. The results of the comparison, is shown in Table 16. This data is plotted in the Binary Graph shown in Figure 27.

Table 16 Binary table, where 1 means Option 1 selected as both Option 2 and Option 3 EMV's are negative

Binary table, where 1 means Option 1 selected as both Option 2 and Option 3 EMV 's are negative									
Option 1 EMV		Initial Investment Values							
		$700.00	$800.00	$900.00	$1,000.00	$1,112.00	$1,200.00	$1,223.00	$1,300.00
Volatility	10.00%	0	0	0	1	1	1	1	1
	20.00%	0	0	0	1	1	1	1	1
	30.00%	0	0	0	0	1	1	1	1
	40.00%	0	0	0	0	1	1	1	1
	50.00%	0	0	0	0	1	1	1	1
	60.00%	0	0	0	0	0	1	1	1
	70.00%	0	0	0	0	0	1	1	1
	80.00%	0	0	0	0	0	1	1	1
	90.00%	0	0	0	0	0	0	1	1
	100.00%	0	0	0	0	0	0	0	1

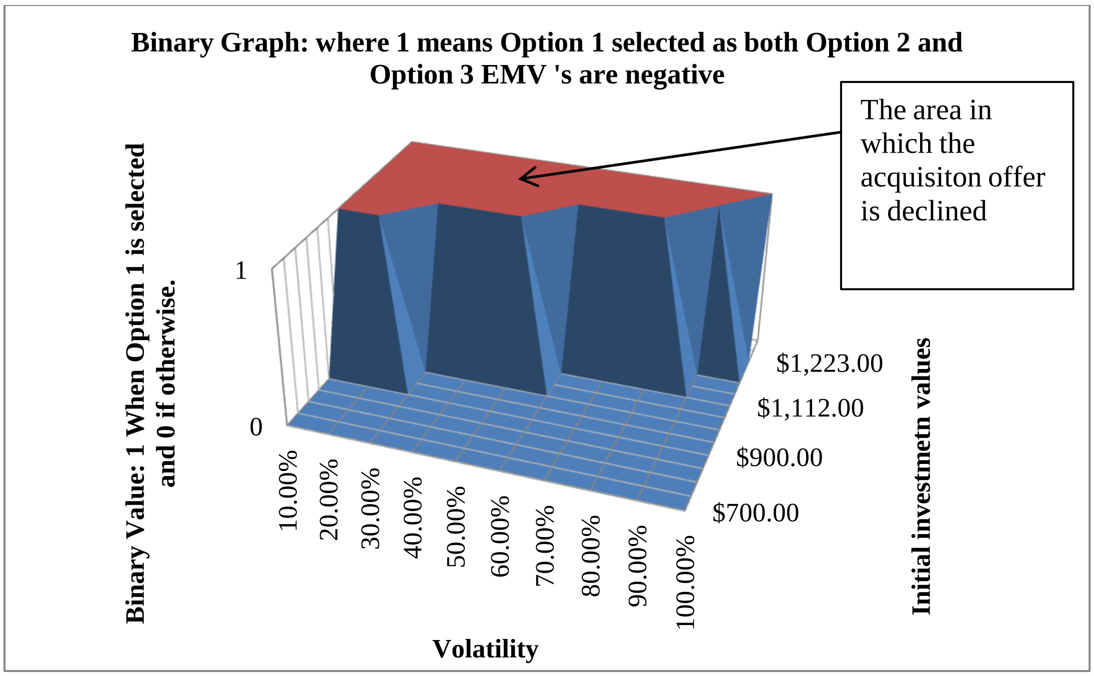


Figure 27 Binary Graph: where 1 means Option 1 selected as both Option 2 and Option 3 EMV's are negative

4.7.8 Two-way sensitivity analysis between the follow up investment value (the Exercise price) for PCM of $ 1B. and the expected value (the Strike price) of $1.7 B., to understand the impact of variation between the two and the resultant Option 3 EMV's.

In modeling valuation of Option 3's EMV, a major role is played by the option value added to the equation for calculating the EMV by the Black and Scholes model. The Black and Scholes model calculates the values of the Strike price and Exercise price. The Exercise price of $1 B., is the price which MU would have to pay to commercialize the PCM and the Strike price ($1.7 B.) is the expected income gained from the investment. To better understand these effects, a two way sensitivity analysis was conducted to study the follow up investment value (the Exercise price) ranging from $700M to $1.4 B. vs. the future gain values (the Strike price) ranging from $1.4 B. - $2 B. Table 17 represents the results obtained from two way sensitivity analysis. Figure 28 plots the results of this sensitivity analysis and indicates where Option 3 EMV's are still positive.

Table 17 Two-way sensitivity analysis: follow up investment (2014) vs. the expected gain from the follow up investment (Option 3 EMV's)

Option 3 EMV outcomes		Follow up investment values. (2014)							
		$700.00	$800.00	$900.00	$1,000.00	$1,100.00	$1,200.00	$1,300.00	$1,400.00
Expected outcome For possible follow up investment	$1,400	($31.58)	($56.06)	($78.05)	($97.94)	($116.04)	($132.61)	($147.84)	($161.89)
	$1,500	$15.21	($10.70)	($34.04)	($55.21)	($74.54)	($92.26)	($108.59)	($123.69)
	$1,600	$62.67	$35.40	$10.75	($11.67)	($32.17)	($51.02)	($68.42)	($84.55)
	$1,700	$110.72	$82.14	$56.24	$32.63	$10.97	($8.97)	($27.42)	($44.54)
	$1,800	$159.32	$129.48	$102.37	$77.60	$54.83	$33.83	$14.36	($3.74)
	$1,900	$208.41	$177.36	$149.09	$123.19	$99.35	$77.31	$56.85	$37.80
	$2,000	$257.94	$225.73	$196.33	$169.35	$144.47	$121.42	$100.00	$80.02

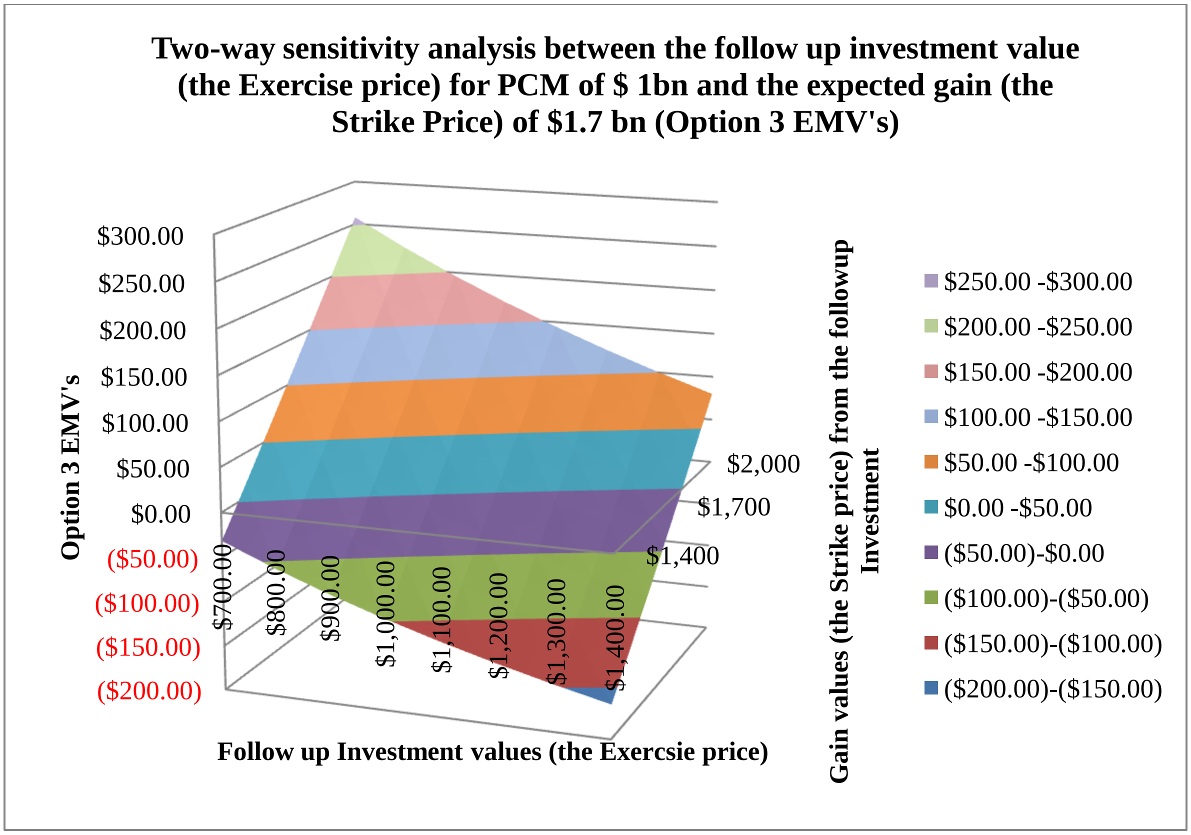


Figure 28 Two-way sensitivity analysis: follow up investment (the Exercise price) (2014) vs. the expected gain (the Strike price) from the follow up investment (Option 3 EMV's)

As expected, one can see that as the investment value increases with a gain in strike price and a decrease in option price. Thus the decision maker would only select values which are positive and yield a higher value than Option 1 and Option 2. This sensitivity analysis would help the decision maker in the year 2014, when MU would have to decide to reevaluate their decision concerning a follow up investment or the Exercise price of the option.

4.7.9 Two-way sensitivity analysis between the follow up investment value (the Exercise price) for PCM of $ 1B. and the expected value (the Strike price) of $1.7 B., to understand the impact of variation between the two and the resultant Option 2 EMV's.

In the modeling for valuation of Option 2 EMV, a major role is played by the option value added to the equation for calculating the EMV by the Black and Scholes model. The Black and Scholes model drives the values of the Strike price and Exercise price. The Exercise price of $1 B., is the price which Micron would pay to commercialize the Phase change memory and the Strike price ($1.7 B.) is the price which is the expected income gained from the investment. So It becomes necessary to better understand at what follow up investment value (the Exercise price) and at what gain value (the Strike Price) would MU be willing to still go ahead with option 2. And it is to be noted here that since the decision to undertake the acquisition of Numonyx was deferred to the year 2011, there is a loss of at least a year's worth of positive cash flows generated by NOR sales.

To understand this relations a two way sensitivity analysis was carried on the follow up investment value (the Exercise price) range from ($700 M. to $1.4 B.) vs. the future gain value (the Strike price) range of ($1.4 B. - $2 B.). Table 18 represents the results obtained from two way sensitivity analysis. And the graph shown in the Figure 29 shows the ranges where Option 2 EMV's are still positive.

Table 18 Two-way sensitivity analysis: follow up investment (the Exercise price) (2014) vs. the expected gain (the Strike price) from the follow up investment (Option 2 EMV's)

Option 2 EMV Outcomes		Follow up investment (2014) values							
		$700.00	$800.00	$900.00	$1,000.00	$1,100.00	$1,200.00	$1,300.00	$1,400.00
Expected outcome For possible follow up investment	$1,400	($236.37)	($266.53)	($293.59)	($318.01)	($340.16)	($360.36)	($378.85)	($395.85)
	$1,500	($183.71)	($215.65)	($244.40)	($270.44)	($294.14)	($315.81)	($335.70)	($354.04)
	$1,600	($130.24)	($163.86)	($194.24)	($221.84)	($247.03)	($270.13)	($291.39)	($311.02)
	$1,700	($76.03)	($111.26)	($143.20)	($172.29)	($198.93)	($223.41)	($246.00)	($266.91)
	$1,800	($21.17)	($57.94)	($91.36)	($121.90)	($149.93)	($175.75)	($199.63)	($221.78)
	$1,900	$34.29	($3.95)	($38.81)	($70.74)	($100.11)	($127.23)	($152.36)	($175.71)
	$2,000	$90.28	$50.64	$14.41	($18.86)	($49.53)	($77.91)	($104.26)	($128.79)

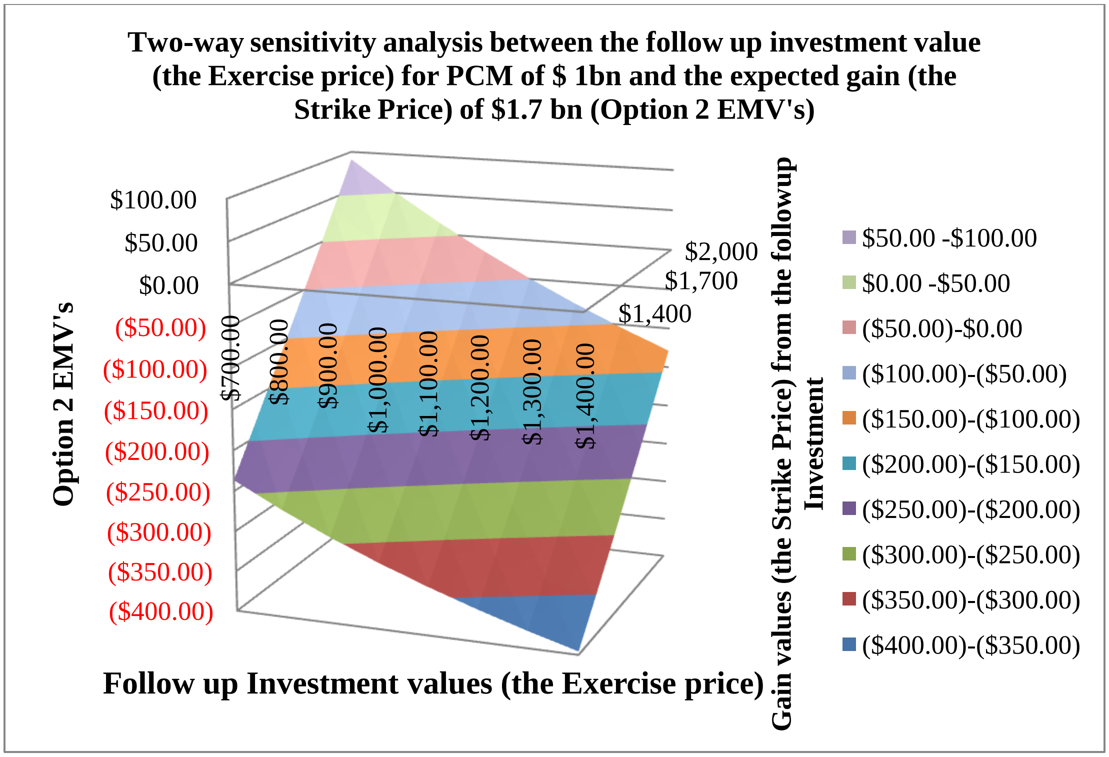


Figure 29 Two-way sensitivity analysis: follow up investment (the Exercise price) (2014) vs. the expected gain (the Strike price) from the follow up investment (Option 2 EMV's)

Looking at Table 18 and also at the data plotted in Figure 29, one can see that positive values for the EMV's exist between follow-up investment values $700M and $1 B. Additionally at a follow-up investment value (the Exercise price) of $1 B. for all the values of strike price (between $1.4 B to $2 B), that the EMV outcomes are negative for Option 2. On the other hand, when the strike price is at $1.7 B., all values for a follow-up investment between $700 M to $1.4 B. are negative, and this outcome can be attributed partly to the loss of the income from the year 2010-2011.

Again, this sensitivity analysis would help the decision maker in the year 2014, when MU might decide to re evaluate their decision concerning a follow up investment.

4.7.10 Two-way Sensitivity analysis between follow up investment values (the Exercise price) and Expected outcome (the strike price) to determine where declining the acquisition offer (Selecting Option1) would provide between value compared to Option 2 and Option3.

In the section 4.7.8 and 4.7.9 the various outcomes at varying follow-up investment cost and expected gain were tested against each other to understand their impact on the EMV's of Option 3 and Option 2 respectively.

Since selection of Option 1, to decline the initial investment, is optimal only when Option 2 and Option3 EMV's are both negative the Two-way sensitivity tables of follow up investment values (the Exercise price) and Expected outcome (the strike price) for Option 3 and Option 2 were compared, namely Table 17 and Table 18.

The condition for Creation of the binary table was that for all the corresponding follow up investment values (the Exercise price) and Expected outcome (the strike price), where Option1 EMV of $0 would be greater than the EMV's of Option2 and Option 3. The results of the comparison, is shown in Table 19. Also The Binary Graph Shown in Figure 30 shows the area where Option1 EMV of $0 is higher value compare to Option 2 and Option 3.

Table 19 Binary table Option1 selection, (Follow up investment (the Exercise price) vs. Expected gain (the Strike Price)) (When Option 1 EMV's are greater than Option 2 and/or Option 3 EMV's.

Option 1 (1 if selected and 0 if otherwise)		Follow up investment (2014) values.							
		$700.00	$800.00	$900.00	$1,000.00	$1,100.00	$1,200.00	$1,300.00	$1,400.00
Expected outcome For possible follow up investment	$1,400	1	1	1	1	1	1	1	1
	$1,500	0	1	1	1	1	1	1	1
	$1,600	0	0	0	1	1	1	1	1
	$1,700	0	0	0	0	0	1	1	1
	$1,800	0	0	0	0	0	0	0	1
	$1,900	0	0	0	0	0	0	0	0
	$2,000	0	0	0	0	0	0	0	0

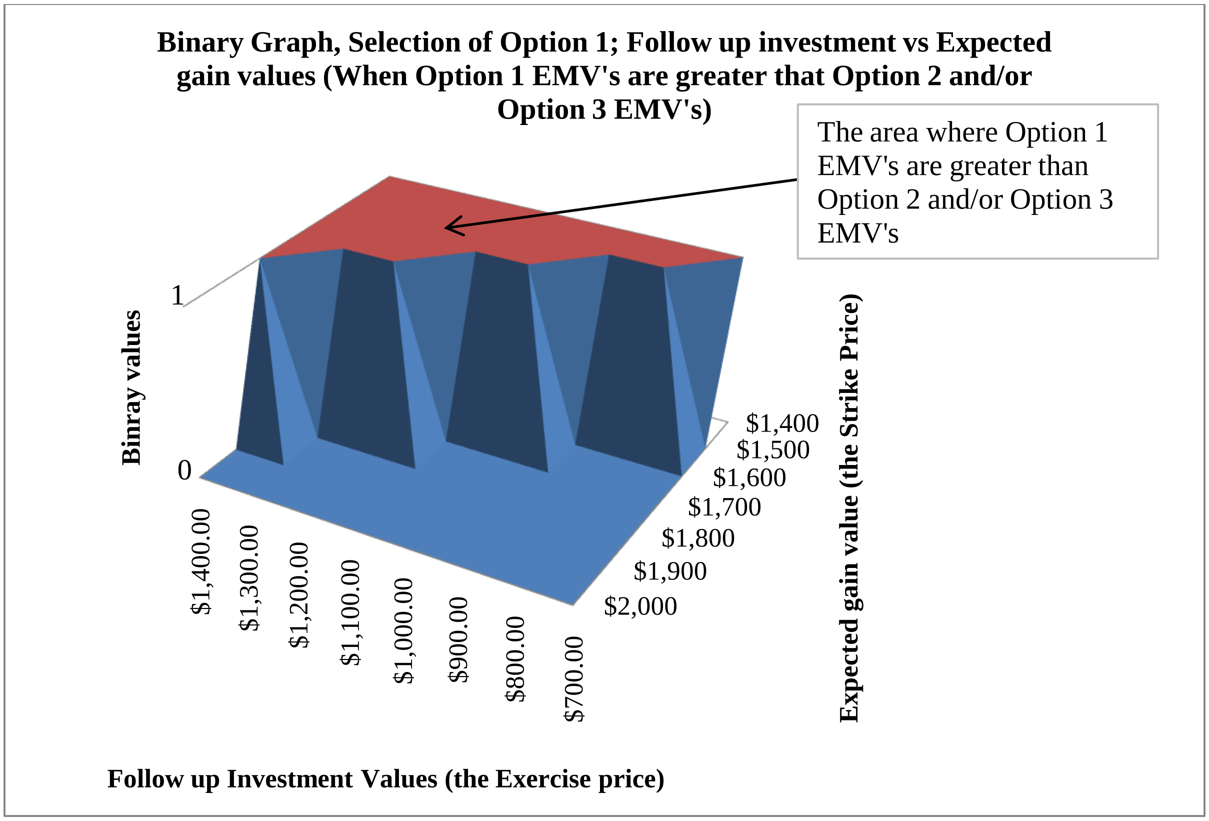


Figure 30 Binary table Option1 selection, (Follow up investment – Exercise price vs. Expected gain – Strike Price) (When Option 1 EMV's are greater than Option 2 and/or Option 3 EMV's.

So from Table 18 and from the graph shown in Figure 30, at an expected gain of $1.4 B. all follow up investment turn out to be negative and thus the decline option or Option1 is selected. The table 19 and the graph shown in Figure 30 can help the decision maker to understand at what expected gain values (the Strike price) and the corresponding value of follow up investment (the Exercise price) would, declining the acquisition of Numonyx would make more sense.

4.7.11 Summary of the sensitivity analysis:

In section 4.7.1, the internal risk probabilities were subjected to sensitivity analysis and the results revealed that, when everything else is kept constant, change in the internal risk probabilities has no effect on the decision making process since option 3 (to invest now) dominates both option 2 (to defer for one year) and option 1 (to decline to invest ever) of the decision tree. And similarly in section 4.7.2 it was discussed that change in the probabilities of losing the acquisition deal does not affect the decision at all, as option 3 again dominates both option 2 and option 1.

In section 4.7.3 through 4.7.10, a series of two-way sensitivity analyses was carried out on the initial investment and follow-up investment amount, the volatility of the investment activities and the strike price return on the follow-up investment. These analyses revealed that the EMV of option 3 goes up as the initial invest decreases and volatility increases. Also beyond the initial investment amount of $ 1.3 B. all values of option 3 are negative which means that everything else kept constant the choice would be to select option1 or the decline option. Similar analysis on option 2 was carried out in section 4.7.4, where the analysis revealed that option 2 EMV's dominates over option 3 EMV's, for all values of volatility and initial investment values below $1.2 B. Option 2 EMV's dominate over option 3 EMV's in the small window between the initial investment amount of $1.2 B. and volatility range above 60%. The significance of this result is that the engineering manager can thus determine that these values are of critical importance, as minor changes might change the decision, and thus more focus is needed in determining these values as accurately as possible.

In section 4.7.5, Table 13 reveals the values where option 2 dominates over option 3 and option1, supporting the afore mentioned discussion, Table 13 reveals that initial investment values and volatility assumptions should be made more accurately to understand the impact of changes in them over the selection of the optimum outcome option.

In section 4.7.6, a two way sensitivity analysis was carried out on the percentage increase in initial investment value and volatility, on the outcome of option 2 EMV's. It was revealed at even at increase in initial investment value of as low as 1%, option 2 EMV is lower than option 3 EMV with volatility value of 64%. This signifies that fact that at higher initial investment values and higher volatility values option 2 is dominated by option 3. This can also be seen in the 3 dimensional graph shown in Figure 26, where the area where option 2 dominates over option 3 EMV of $32.63 million is very small and exits only at higher volatility values and lower increase in initial investment values.

In the section 4.7.7 comparison between two sensitivity analysis outcomes of option 2 and option 3 shown in Table 11 and Table 12, to understand where selection option 1 or declining the acquisition offer completely would be the most optimum solution. The comparison results were shown in Table 16 and Figure 27. The results revealed that when the initial investment amounts go beyond $1.3 B. it is best to decline the option for all values of volatility. And also between the initial investment range of $1 B. to $1.2 B., declining the offer is the best option for lower values of volatility as shown in Table 16

Similarly sensitivity analysis was carried on the expansion option that MU would gain on acquiring Numonyx. In section 4.7.8 and 4.7.9 two way sensitivity analyses was carried out between the follow up investment for expanding Numonyx for PCM production at the end of the year 2014 and the expected outcome of this future investment for option 3 and option 2 respectively. The analysis revealed that option 2 EMV would be positive only for higher gain from the follow up investment and at a lower initial investment (See Table 18), whereas for Option 3 the EMV values were higher and better performing comparatively (See Table 17)

In section 4.7.10, a comparative analysis was carried out between the EMV outcomes of option 3, option2 and option1, when the follow up investment ranges are compared with follow up gains. The analysis revealed that higher initial investment values and lower gain values option 1 becomes dominant over option 2 and option 3 (See Table 19 and Figure 30).

By doing such an analysis many factors about the selection of options were revealed. Such an analysis can aid the Engineering manager to better understand what variables are very sensitive, thus the engineering manager not only can focus more on such variable which might be sensitive but also develop contingency plans. For example, it was revealed that EMV outcomes can turn negative if the follow up gain value is affected negatively. With such knowledge the engineering managers can focus on the factors that affect the gain from expansion and predict their behavior. If in the future is evident that such factors might get affected negatively, the engineering manager can devise an exit strategy or take necessary steps to avoid losses.

5.0 Conclusions

5.1 Summary

During the literature review it became increasingly evident that real options analyses and decision tree analyses can be used in liaison to better understand investment decisions. This was particularly evident for new technology investments since it is very difficult to assess all aspects these investment decision(s) intelligently. As there are many variables involved with new technology acquisition or R&D investments for new technology the chances of failure are always significantly higher. In the traditional analytical techniques, to counter this higher risk of failure, generally the discount rates employed are increased. The problem with such high discount rates is that these discount rates generally do not do justice to low risk parts of the investment.

Using real options along with decision tree analyses, the decision maker can overcome at least some part of this problem since the decision maker can separate internal risk from external risk by using probabilities instead of a universal discount rate as in traditional discounted cash flow analysis techniques.

The benefit of such an analysis lies in the flexibility it provides to the decision maker, while providing a better and clear view of different choices the decision maker faces during decision making. With the incorporation of decision tree analyses and the Black and Scholes option pricing method, Engineering managers can also incorporate simulation techniques like Monte Carlo simulation to better understand the impact of the uncertainties on the probabilities used in modeling the investment decisions.

5.2 Contributions

In the thesis, literature was reviewed to gain a better understanding of the real options theory. The literature review began with the understanding of the evolution of real options from its conceptual roots in particle physics (Brownian motion) to the application of the real options concept in evaluating investment decisions. Along with real options literature, other concepts including economic utility theory and decision tree analysis were also reviewed. In the thesis, thus a tool as presented which combines decision tree analysis and real options analysis, which was used for evaluating technology investment decisions. This tool, as introduced, can be used by engineering managers for evaluating investments in technology projects under uncertainty.

This knowledge gained was then applied to a real case study: the acquisition of a Swedish flash memory maker Numonyx by the American memory manufacturer MU using real options analyses. To evaluate this case, data were collected, several assumptions were made based on available information, a complete analysis was conducted, and then several sensitivity analyses on the assumptions were performed.)

Some of drawbacks were also identified in the application of real options concepts, in combination with decision tree analysis is that, if multiple projects are to be considered together, the modeling of the decision tree becomes very complex and, potentially, confusing. Also the difficulty in predicting the volatility of the project in terms of the payoffs makes it difficult to accurately predict the accurate project pay offs.

5.3 Limitations and future work

Limitations of this thesis include that: Due to lack of real data, much of the analysis is based on hypothetical data. Though sensitivity analysis has been performed, this work could make a more important contribution if it was built on actual data. The use of decision tree to calculate options value has been reviewed and studied extensively. However, due to the lack of a comparative technology to serve as a “twin security,” the decision tree method could not be applied and demonstrated using the

MU/Numonyx case. In the future, if a data on a comparative technology became available a comparative options analysis could be carried out. For example: MU's competitor Samsung's PCM technology can be used as a comparative twin security, which can be incorporated in the decision tree analysis following the procedure discussed in section 3.3 and also MU's utility curve could better aid in calculating the optimum expected utility values.

While, this thesis focused on applying a 'learned method' to a real world situation, future work can look into how the method itself could be improved. Real options analysis is one of the very promising financial evaluation methods and does provide the engineering manager with a better look at the viability of a project under a set of various given circumstances. However, at this time the complexity of modeling a real options scenario is the main reason why it has not been incorporated extensively to date. One of the limitations decision tree and real options analysis is the complexity of the modeling which make it difficult for the decision maker to identify errors in the analysis.

Research needs to be done in areas where real options can be applied to multiple projects and strategies which are competing against each other. Some research has been done in this area by Angelou and Economides in [19], where they have used Game theory to address the risk associated with competition in a particular environment. In their report they have suggested that multiple players or the market as a whole can be used to analyze business alternatives under the threat of competition. In the future such game theory approach can be extended to decision tree analysis in order to compare different branches using Game theory.

Also there still needs to additional research done in the Black – Scholes model, regarding volatility. All the other variables in the Black and Scholes model, except volatility, can be easily calculated. At this time, the real difficulty in getting the most accurate value is in calculating the most accurate volatility value, which in turn demands very accurate forecasts for the future project pay offs in all probable outcome scenarios, the crux of the problem in itself.

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