Valuing New Economy Companies
using Real Options Theory with Visualization

by

Arturo Manuel Rodriguez Ramirez

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Signature of Author: ____________________________

Arturo Manuel Rodriguez Ramirez
Department of Electrical Engineering and Computer Science
February 6, 2001

Certified by: ____________________________

S. P. Kothari, Thesis Supervisor
Gordon Y. Billiard Professor of Accounting and Finance
Alfred P. Sloan School of Management

Accepted by: ____________________________

Arthur C. Smith, Chairman, Committee on Graduate Theses
Department of Electrical Engineering and Computer Science
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ABSTRACT

This paper concerns the valuation of new economy companies using real options models and ideas. Real options theory determines the value of any economic activity where uncertainty and flexibility are present, and where another activity with the exactly same payoff as the former can be valued. New economy companies are portfolios of uncertain projects combined with some certain cash flow streams. This uncertainty explains their volatility, rates of growth and high multiples as normal parts of their development. It also explains market bubbles and crashes and other economic events in the same terms. In the real options framework expenditures in capital equipment and some intangibles –such as R&D, and strong sales and marketing organizations– are really investments in growth. To make the study of real options more intuitive and informative we use and endorse the use of visual representations in the form of diagrams and graphs.

Thesis Supervisor: S. P. Kothari
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1 Introduction: The New Economy

To understand the motivation for this paper it helps to set ourselves in the context of contemporary market history. At the time of this writing it is January 2001, and in the past two years new economy companies have experienced their two most extreme equity price performances ever. 1999 saw the heavily new economy weighted Nasdaq Composite Index appreciate by more than 80%, peaking at a little above 5000 in March 2000, only to retreat in 2000 by more than 40%, bottoming at a little under 2300 in January 2001. In individual issues some large and many smaller technology names gained hundreds of percent returns in 1999 -these include Qualcomm, Oracle and many Internet companies- only to see their value fall down precipitously the following year. Many Internet high fliers, including the most profitable companies, lost 80% or even 90% of their market value from their highs. Yahoo!, a company that had risen steadily since IPO by hundreds of percent per year and the leading web media property fell from a high of about $250 a share to the 30s today: an 88% drop. Similar examples can be found in Inktomi, Ebay, Amazon.com, and others all down more than 80% from their March 2000 highs. Even established PC industry companies such as Microsoft, Intel and Dell, all fell more than 50% from their highs. Did the conditions of the world change so quickly in a matter of months? Where the 1999 prices or the 2000 ones the correct values of these companies? What are the true values of these new economy companies?

One of the reason this has been such a difficult question to answer is that these companies thrive under conditions of great uncertainty. They are companies that grow very fast their top and bottom lines, that have unsettled technological issues that get resolved by the day, that ship products in markets with not yet clearly defined standards and where competition is intense, and that they generally develop under conditions where they can make or break billions of dollars in revenues and earnings in the matter of just a few years. In short they must grow in a high competition environment where flexibility and adaptability is the key to survival and success. Management and technology plans can not be done for more than two years ahead, and product cycles last not much more than a year.

Under these conditions traditional ideas of management and valuation break down. The companies’ management must learn to take real time decisions to thrive; and
thus they can not by any means guarantee courses of action based on uncertain future events. Put together the unpredictability of their product and service markets with that of the companies’ management, and valuators and investors suddenly face the hapless task of pricing companies whose future you can not see in one year time, with tools that have been designed assuming it is known what companies will be doing in five years time. This is the dilemma valuators and the financial markets face when trying to apply discounted cash flow methods to the new economy. The result is volatile markets.

What we need is a theory that allows us to price uncertainty and flexibility. This theory exists and was developed for financial options by Fisher Black, Myron Scholes, and Robert Merton in the 70s, and later extended to the world of real projects beginning with the work of Stewart Myers. It is option pricing theory. Real options pricing theory is used to value uncertain projects and some companies today. What we need is to further systematize the process of valuing entire companies. Some of these companies —for example startups— will be straightforward to value using real option project techniques since they are in essence single project companies. Larger more mature and diversified companies will be more complex and will require a more flexible approach. We intend to discuss various issues relevant to this process.

In particular we intend to focus on understanding where is value coming from and how can it be estimated without too much need for mathematical sophistication. We intend to explain and define what truly is a new economy company, we intend to understand these companies in a light that combines valuation with strategy, and we intend to help our understanding by diagrams and graphs that condense and visualize the relevant information. But from this what we hope to transmit most is that beyond its value for equity pricing real options theory is a most powerful mental model for both understanding value and implementing strategy.

Some great investors —like Warren Buffett— have shied away from new economy companies because they feel uncomfortable predicting where they will be in any amount of time. What we hope with this paper is to contribute to tackling this problem so that not only stock pickers, but investors and entrepreneurs of all sorts, will start thinking of uncertainty and flexibility like their allies from which they can profit even more than they can loose.
2 Literature Review

2.1 Option Pricing Theory

The development of real option theory would not have been possible had option pricing theory not been given a start by Fisher Black and Myron Scholes together with Robert Merton in their seminal 1973 papers “The pricing of options and corporate liabilities” (1) and “Theory of rational option pricing” (2). In the papers they show that the relationship between the price of stock and the option on it is a partial differential equation subject to boundary conditions whose close-form solution in the case of a single contingent variable and expiry date is the Black-Scholes equation. An important requirement for the correct solution is that the law of one price holds. That is equivalent to saying that there should be no arbitrage opportunities.

John Cox and Stephen Ross, later together with Mark Rubinstein, developed the binomial option-pricing model. In their papers “The valuation of options for alternative stochastic processes” (3) and “Option pricing: a simplified approach” (4) they introduce the idea that option prices should be unique and independent from each investor’s risk preference. They also develop an amenable alternate way of computing option prices that is usable in a wide range of applications and will be the foundation of our work in this paper.

Many other important contributions to option pricing theory have been made, but we will focus on those of greater relevance to real options here. For general books on the subject of option pricing theory Cox and Rubinstein’s own Options Markets (5) is considered among the best available. Another good text is John C. Hull’s Options, Futures and other Derivatives (6).

2.2 Real Options Theory and Applications

Stewart Myers was the first to coin the term “real options”. In his seminal 1984 paper “Finance Theory and Financial Strategy” (7) he discussed the issues dividing the two branches of management science and the inconsistencies that must be resolved before they can be united. He argues that the inadequacy and misuse of the Net Present Value (NPV) model coupled with financial theorists and strategists’ lack of a common theory of firm value is at the root of the problem. Myers correctly points out many of the faults of
NPV in valuing projects that provide no immediate cash returns but that nevertheless strategists agree are of great value to the firm. Among them the misuse of NPV itself accounts for much of the error but he nevertheless explains that even if perfectly well implemented NPV would still fail to capture "the links between today's investments and tomorrows opportunities". Because of that he concludes the paper calling for the development of a unifying theory of value that could be used across both fields: "Strategic Planning needs finance. Present value calculations are needed as a check on strategic analysis and vice versa. However, standard discounted cash flow techniques will tend to understate the option value attached to growing profitable lines of business. Corporate finance theory requires extension to deal with real options."

At around the same time W. Carl Kester published "Today's options for tomorrow's growth" (8). In it he adds to Myers' argument by expanding the ideas behind real options theory. He uses an example were NPV thinking lead management to the wrong decision, which would have been prevented if they had analyzed the problem using options pricing theory instead. He explains that various factors -including increased project cash flow volatility, increased interest rates, and increased length of time that the project can be deferred- add to project value. This is in contradiction to NPV arguments but is the natural outcome of options thinking. He also points out that real options can be either proprietary to the firm or shared with competitors thus giving birth to strategic growth options theory. He further distinguishes between many other important types of options such as simple and compound, and expiring and non-expiring. And most important he argues that options valuation is in the interest of the firms shareholders at all time horizons: "Because investment decisions today can create the basis for investment decisions tomorrow, capital allocations made in any year are vital steps in the ultimate achievement of strategic objectives. By the same token, a long-range plan necessarily implies the cultivation of particular investment opportunities and can have a direct, dollars and cents impact on a company's stock price in the near term as well".

In "Valuing Managerial Flexibility" (9) Lenos Trigeorgis and Scott Mason provide one of the early papers on how to apply real options theory from a practical point of view. They also defend real options theory from decision tree analysts' by showing that real options theory incorporates the market opportunity to trade and borrow and
therefore is more economically correct. They once again argue that managerial flexibility is an element not present in NPV calculations and that the resulting payoff asymmetry can not be successfully captured by NPV techniques. They introduce the use of decision trees in analyzing the future payoffs of contingent projects but argue against going all the way with decision tree analysis because of the difficulties of determining the right discount rate. Instead they use the fundamental option principle of project payoff replication through the use of a twin security and risk less bond. They provide examples of how to compute the values of various types of real options, including those to defer investment, expand or contract.

In one of the more recent papers (1995) on real options theory “The Options Approach to Capital Investment” (10) Avinash Dixit and Robert Pindyck set out to explain several of the faulty assumptions of NPV and how real options theory addresses this issues. In particular they point to the fact that NPV assumes investment decisions are reversible and can not be deferred, while in many cases neither of these assumptions holds true. They argue that often it is valuable for a company to create options for itself in order to potentially capture value in the future, and that often it is worthy to delay exercising the option until all the necessary information is available. As examples they explain that options thinking proves that it may be more profitable for ongoing companies that are loosing money to continue operations --contrary to NPV thinking-- by showing that incurred costs are already sunk and that they give the company rights to earn future profits as long as the productive assets are not sold off. Furthermore they argue that financial markets value more highly investments that create options --such as the new economy startups-- than those that exercise them. Also they argue that many options underlying assets are intangibles, such as know-how and brand, as well as the more obvious assets of production facilities or resources.

In his 1996 paper “Applying ‘Options Thinking’ to R&D Valuation” (11) Terrence Faulkner argues that the ideas of real options theory must be used to value knowledge creating projects and to think about strategy. In particular Faulkner emphasizes that even decision tree analyses that are based on option ideas are an acceptable way of computing ‘option thinking’ values. This method involves assigning probabilities to uncertain events and computing the expectation of the outcomes and their respective contingent decisions.
But more significantly this method leads managers to think strategically in terms of flexibility, phased investments, long-term focus, and the value of intangibles. Faulkner is careful to point out however that options thinking can also be misused to casually justify unprofitable projects.

A good introduction to the uses of real options thinking in corporate strategy is Leslie and Michael's (1997) paper "The Real Power of Real Options" (12). The authors set out to market the idea of real options as a strategic tool for managers engaged in capital expenditure decisions where there is uncertainty in the future payoff. Their exposition is centered on the analogy of real and financial options, and as such they explain the Black-Scholes option pricing formula as applied to real options. They explain the meaning of the six parameters of Black-Scholes in real options, and the strategic measures that management can take in manipulating these parameters to maximize option value. Finally they go over two examples in the UK energy sector where the companies realized substantial shareholder value through the use of real options thinking.

Timothy Luehrman’s “Investment Opportunities as Real Options: Getting Started on the Numbers” (13) provides a methodology for managers not necessarily deeply knowledgeable of the mathematics or economics of option pricing theory with a way to do easy real option value estimates. Like Leslie and Michael’s paper it relies on the foundations laid out by the Black-Scholes equation to provide the intuition and methodology. Nevertheless Luehrman develops a transformed version of NPV (called NPVq) that together with a measure of “cumulative volatility” —which incorporates volatility and time—provides all the information available in the five basic Black-Scholes parameters. These two parameters in turn are used to look up in a table the value of the option as a percent of the “stock” (present value of underlying assets).

Kulatilaka and Perotti develop a mathematical model for real options in markets with imperfect competition in their (1998) paper "Strategic Growth Options" (14). In it the authors prove that acquiring strategic growth options can serve as a powerful deterrent for competitors to invest in capacity or even enter the market and therefore results in the option holding company having a greater market share and a lower cost structure, as is seen in many technology markets. This result is dependent however on the level of "strategic advantage" intrinsic to the product or service market.
Laura Quigg’s (1993) “Empirical Testing of Real Options Models” (15) is the second empirical work to prove that investors do value real options and act in a rational economic fashion as the theory would suggest. Her work is based on the study of Seattle’s land market. The only preceding empirical work was Paddock, Siegel and Smith’s (1988) “Option valuation of claims on real assets: The case of offshore petroleum leases” (16) which concentrates in offshore oil production licenses.

Two Harvard Business Review papers on new economy uses of real options theory are N. Nichols “Scientific management at Merck: An interview with CFO Judy Lewent” (17) and W. Sahlman’s “How to write a great business plan” (18). These two papers give practical examples of the uses of real options within the contexts of R&D projects in a biopharmaceutical company, and the valuation of startup ventures from the point of view of the venture capital community. They are among the more recent examples of practitioners pushing for the dissemination of real options theory among their colleagues.

For complete treatment of real options theory Amram and Kulatilaka’s Real Options (19) is an excellent text. They condense many of the ideas developed by others and themselves over the past decade and a half and published in research papers into a single readable volume. It also includes an excellent list of references to the papers and texts they used. Older works that concentrate on real options are Flexibility, Natural Resources and Strategic Options (20) by Brennan and Trigeorgis, Real Options-Managerial Flexibility and Strategy in Resource Allocation (21) and Real Options in Capital Investments: Models, Strategies and Applications (22) both by Trigeorgis, as well as Investment Under Uncertainty (23) by Dixit and Pindyck. Two treatments of real options in valuation and corporate finance texts are “Using Options Pricing Methods to Value Flexibility” in Valuation, Measuring and Managing the Value of Companies by Copeland, Koller and Murrin (24) and “Applications of Options Pricing Theory” in Principles of Corporate Finance (25) by Brealey and Myers. For more basic readers a good introductory book to valuation that does not go as far as including real options is Business Analysis and Valuation Using Financial Statements (26) by Palepu, Bernard and Healy.
3 Real Options Review

3.1 Uncertainty, Flexibility and the Law of One Price

Net present value (NPV) is the most commonly used technique for valuing investment projects today. It states that the value of investment projects must equal the sum of all expected cash inflows and outflows the project will generate properly discounted at the project’s cost of capital:

\[ NPV = \max_{i=0} \left[ \frac{E(CashFlow)}{CostofCapital}, 0 \right] \]

Equation 3-1: The meaning of net present value.

The cash inflows include all cash revenues and the outflows include all cash expenses and capital expenditures necessary to earn the revenues. The net present value technique works best when these inflows and outflows projections are as accurate in time and magnitude as they can be to the future outcome of their values. The cost of capital in turn includes the weighted expected returns of investors of all debt and equity that the firm has issued for the project. This risk-dependent weighted cost of capital should be set as close to possible to the real return that investors expect. Estimation of both cash flows and cost of capital is often fraught with problems due to the use of most likely –i.e. median, not expected- cash flow scenarios, worst-case cost of capital requirements, and other common biases. Properly addressed they can be avoided, but biases and interests often work together to ensure that in some applications NPV estimates are often far from the future outcomes or objective expectations. In addition, due to neglect, NPV is often misused in another way. Rarely is account taken of the cash flow impact that the project under study will have in other current company projects and vice versa. Like with the cash flow and cost of capital issues however there is no fundamental reason why the technique itself is at fault here. In principle all three problems can be avoided with proper care.

There is however a fourth complication that NPV applications encounter and it is how to include the project’s impact on future company business. NPV assumes that there is no uncertainty, and therefore that either we can reasonably predict any impact that the project will have in future operations or that there will be no impact to worry about.

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Because of this —NPV says- we can take final investment decisions today with total confidence in the most profitable outcome and no possible impact —positive or negative—in any future operation outside of the project. All NPV based investment decisions can thus in principle be, and are assumed to be, final since they do not accrue any possible unknown benefit or cost to the company. The problem is that in practice the certainty assumption breaks down since valuators do not know what the future could bring in terms of markets, opportunities, competition, prices and other variables of interest. Therefore how can they build an omniscient NPV model when they may not know what the future may bring to the cash flow of the project itself? Recognition of uncertainty in the real world is one of the reasons for the use of real options theory.

Once we have recognized uncertainty, another reason why NPV is at fault is that management should be able to act flexibly to the now uncertain outcome of future events. As we noted NPV also assumes finality of investment decisions, even of those to be expended in the future, once we have committed to a project. To tackle both these issues, an alternative approach to NPV called decision tree analysis (DTA) allows for both uncertainty and managerial flexibility. It is based on a tree like structure of the future, where each branch of the tree represents one possible future outcome and the corresponding managerial decision that maximizes firm value. Each branch is assigned an outcome probability and value is computed by probabilistic expectations. So if DTA deals with future uncertainty and managerial flexibility why is it not yet enough?

\[
\text{DecisionTreeValue} = E\left[\max_{i=1}^{M} \left( \frac{\text{CashFlow}}{\text{CostofCapital}}, 0 \right) \right]
\]

Equation 3-2: The meaning of decision tree analysis.

The answer is that DTA does not take into account the third and final reason why NPV fails to match the accuracy of real options. Neither accounts for investors' opportunity to trade and borrow in the financial markets. The basic premise behind this opportunity is that there exists a portfolio that an investor is able to construct through financial and investment operations that should give rise to exactly the same payoff as the project itself. Because this portfolio and the project are economically indistinguishable they should be worth the same, or else arbitrageurs will bid up one and down the other until there are no more risk-less profits to be made from the operation. Therefore after no
more than a finite amount of time the law of one price must hold. DTA –although it recognizes uncertainty and flexibility- does not enforce the law of one price.

We conclude that NPV fails to describe the time series relations between projects on three counts –uncertainty, flexibility, and the law of one price- and that DTA, an ad hoc correction to NPV, still fails at properly describing the time series relations through the failure to adopt the law of one price. Real options theory properly addresses all of these issues. This does not mean that NPV and DTA are useless theories that should be discarded altogether. As we will see later derivatives of NPV are still needed as a valuation tool for safe cash flows that have little impact on other company operations. NPV and real options merely describe different aspect of the company. Similarly DTA may serve as a useful shortcut to approximate real options values when necessary information is lacking, or the precision of the project value figure may be less important than arriving at a quick and easy estimate. As for real options it should be noted that although it is a great valuation tool its worth extends beyond it to include its implications for corporate strategy.

3.2 Option Fundamentals

Above we have showed why the NPV rule is not appropriate to value many company projects and why a real option model is needed to correct for its deficiencies. Now we need to review some of the basic properties of options, so as to understand how their value arises.

An option is a contract that gives its holder the right, but not the obligation, to execute a transaction at or before a certain date. Common types of options are the options to buy or sell financial assets publicly traded in the financial markets, the options to purchase common stock often awarded as part of compensation packages, and contractual options to purchase durable goods and real estate. Of these the later are in fact real options, in that they represent the right to purchase a real asset. Other real options are the right a company has to develop a new product, based on research that has been done in its labs, or the right to distribute an existing product in a new market. The ability of companies to adjust production levels can also be modeled as a portfolio of options, and many other examples abound.
3.2.1 European versus American Options

There are two main types of options as classified by when can they be exercised. If the option holder has the right to execute the transaction at any date before expiration, the option is called an “American” option. On the other hand, if the option holder only has the right to exercise the option at the expiration date, the option is called a “European” option. American options are commonly seen traded in financial markets, though both types of options are common imbedded in contractual clauses. Real options also come in both flavors, but just like financial options it is common to assume all options are European for simplicity of computation. This is motivated by the fact that only the payoff at maturity needs to be known for European options, since the European option holder can not realize any other payoff before that date.

3.2.2 Call and Put Options

An even more important taxonomy of options is whether they give their holders the right to buy or to sell an underlying asset or cash flow. A “call” option gives its holder the right to buy the underlying asset at a specified price — the strike price — in the future at or before a certain date — the expiration date. Because of this a call option has nonzero value at the expiration date if the underlying asset is worth more than the strike by the exact difference of these two values. The possibility of the payoff from the call having a positive value in the future gives the instrument a positive value today even if its current payoff would be zero. Similarly the possibility that the payoff from the call will be even greater in the future gives the instrument a value greater than its value if exercised profitably today. Thus calls are always worth at least as much as their current payoff but greater than this payoff before the expiration date. Most types of practical real options are modeled by call options. These include options for growth, deferred investments, expansions, extensions, etc.

The other type of option, called a “put” option, gives its holder the right to sell an underlying asset at a specified price — the strike price — in the future at or before a certain date — the expiration date. Thus a put option has a nonzero value at the exercise date if the underlying asset is worth less than the strike price by the difference between the two. And just like call options put options are always worth as much as their payoff but more so if
there is still time remaining till the expiration date. Common types of put real options are exit options, options to contract, and options to shorten the life of assets.

3.2.3 Long and Short Option Positions

One key characteristic of options, like any financial asset, is that they can be bought—also called to long an option—, and that they can be sold even if we currently do not own the option as long as we make a promise to deliver it upon request, or alternatively deliver immediately a borrowed option that we must replace—this is called to short an option. Thus we can create not only a net positive—or long—exposure to options but also a net negative—or short—exposure. Holders of short positions are bound according to the rights and wishes of the long position and therefore they must receive a payoff for their trouble. The payoff they receive is the value of the option, which they receive from the long position in order to create the contractual obligation. In the case of “synthetic” real options—or options that are not part of a contractual agreement between two parties—there often is no clearly defined short position. This short position really is a portfolio that is distributed among various holders in the markets. Nevertheless short real option positions do exist in contractual agreements and it is a known fact to us that the value of the option must be the same to the short and long position.

3.2.4 Option Payoff Diagrams

The payoff of options can be visualized using diagrams. These diagrams represent the potential cash value of exercising the option at the expiration date as a function of the value of the underlying asset “S”. Their main characteristic is the presence of the strike price “K” at which there is a kink, or change in slope, of the payoff function. For a long put there is a 45 degree line prior to the strike price commencing from a value equal to the strike price itself—the value that the option would have if the price of the underlying asset at the expiration date were zero—to a value equal to zero at the exercise price and after. For a long call the forty-five degree line begins at the strike price, since a call is worthless at the exercise date if the price of the underlying asset is less than the strike price and after the underlying asset surpasses the strike its value grows linearly with the asset.

It is also possible to visualize the payoff to holders of short positions. Given that payoffs are symmetrical to longs and shorts, that is that the earnings of a long are the
losses of a short and vice versa, the payoffs of shorts are the S axis reflection of the payoffs to longs. Thus short calls have constant positive payoffs until the value of the underlying asset reaches the strike price at which point the payoff starts decreasing dollar for dollar with the rise of the underlying asset value. Similarly the short puts will have a positive payoff above the strike price but their payoff will decrease dollar for dollar with each dollar decrease in the price of an underlying asset.

![Diagram of Payoff](image)

Figure 3-1: Payoff diagrams of long and short call and put positions. C and P are the prices paid for the options, K is the strike price, and S* is the value of the underlying asset at the expiration date. Note that short positions are mirror images of long positions over the S* axis.

### 3.2.5 Option Portfolios and Fractional Options

Options may in fact be grouped together into portfolios. In financial markets this is often done in order to construct specific payoff scenarios that would not possible by simply taking long or short positions in single calls or puts. Thus for example a short put
and a long call with the same strike may be used to construct a long forward position. A long call and a short call with different strikes may be used to construct vertical spreads. Also a long call and long put with the same strike price may be used to construct a bottom straddle. All of these are examples of synthetic derivatives: an instrument that can be composed of elementary long and short put and call positions.

In the real options world put and call positions can also be combined together with positions in their underlying cash flow to create desired payoffs. Thus a company may hedge its risk exposure to changes in the price of a required input by using a combination of puts, calls and the productive asset that resembles the payoff of a vertical spread. This is the case of switching and scalability options in which the company that holds them can use long calls to initiate the use of productive assets, and short puts to terminate their use. As we will see later when studying scalability options, Dell Computer's just in time manufacturing process is a real time use of the scalability option it holds on its productive assets.

A portfolio of options may in fact contain just fractional options. In financial options such a portfolio may be composed by buying a certain number of options, say ten, and then selling interests in such portfolio piecewise, say to twenty interest holders. In real options they arise naturally due to fact that some of the benefits of the changes in the price of the underlying asset accrue to other parties other than the option holder. The main property of fractional option holdings is that changes in the payoffs are no longer dollar-to-dollar with respect to changes in the underlying asset, but rather some-number-of-cents to the dollar. Thus for example the holder of half a call on the revenues of a certain microprocessor will only receive half a dollar for each extra dollar that the revenues exceed the strike price. Therefore it serves to model the effect of costs of goods sold and other associated project variable expenses on the increased revenues of companies. Thus in the case where the underlying cash flow or stock is used to model the revenues of a project, the strike price is used to model the fixed costs, the ownership of just a fraction of an option is used to model the variable costs.

In terms of their value half an option is only worth half a full option, and each fraction is only worth whatever fraction of an option it is. The valuation significance of this realization is that Software and internet media firms, or any firm that sells pure
information, that generally own full options since their variable costs are practically zero, should sell at higher multiples than Hardware or internet retail firms, who incur substantial variable costs for each extra unit sold and thus own only fractional options. Interesting cases in point are Intel and Microsoft each of which has comparable revenues and similar R&D expenditures -a proxy for fixed product costs. Of the two Microsoft has traditionally commanded a higher multiple in order to take into account its lower fixed costs (lower strike) and higher gross margins (larger fraction of an option).

The issue of fractional options has only left us with one question to answer. Like in financial options, can anybody own more than one (identically equal) real option on the same cash flow? The answer is no because in our model where $S$ represents the potential revenues of a project it is impossible to construct a cost structure for the project that will leave the company a profit greater than its revenues. Financial leverage might increase return on equity investment, but that figure is not to be confused with gross margin or net income for the project.

### 3.2.6 Put-Call Parity

The relationship of put-call parity allows us to value the right to sell a cash flow if the value the right to buy it is known. Conversely it allows us to value the right to buy a cash flow, if the value of the right to sell it is known. In financial options its significance is that if the price of either a call or a put and its associated stock and debt securities are known the value of the other option can be deduced without resorting to first principles. It also has the value that in the case where there is mispricing by the financial markets it is possible to clearly see the arbitrage opportunity to be taken advantage of.

$$C = P + S - D - K * r^{-t}$$

Equation 3-3: Put-call parity relation. Allows us to value the call of an asset with a strike price equal to that of its corresponding put if we know the value of this put, plus the present value of the asset and the price of a risk less bond of the same maturity as the options.

The potential significance in real options of the put call parity is analogous. Should we know the price of either the put or a call on a project we should be able to price the other, and if we have the price of both we should be able to check for arbitrage opportunities.
3.3 Option Pricing Theory

We have reviewed many of the fundamental properties of options. What are there basic types, what we can do with them (long or short), what kind of payoffs they have, etc. Now we proceed to review pricing methods. Though what we studied in the previous sections is of invaluable help in understanding options and setting up option valuation problems we also need to have the computational tools necessary to price option projects. This we will achieve mostly through the use of the binomial method. We will also provide the Black-Scholes formula and its strategic meaning as part of this subchapter.

3.3.1 The Binomial and other Decision Tree Option Pricing Methods

The binomial method is based on three main premises that also serve to inspire the method of solution. Our options are written on an underlying asset or cash flow “S”, often call the “stock” or “commodity”, that changes value at discrete units of time in a discrete fashion and that such price changes are out of the control of the firm. In other words this asset or cash flow operates in a perfectly competitive commodity like market. The second premise is that management reacts to these changes in price in an economically rational manner. Thus they choose to exercise their options only when and always when it is optimal. The third is that investors have the ability to construct a market portfolio that exactly replicates the payoff of the option and that therefore they will only be indifferent to buying the portfolio or the option when they are priced the same. Recalling subchapter 3.1 we see these three premises in fact correspond to the three reasons why real option valuations can be more accurate than NPV methods. But moreover these three methods correspond to the three main elements and steps in the binomial method solution process that we will describe below.

3.3.1.1 The Event Tree

The binomial option pricing method is based on the simplest possible representation of the change in price of the underlying asset. Two of its main assumptions are that the underlying asset can only change price in discrete units of time of equal interval and that in such price changes it can only take two new possible prices: hence the name binomial. In its simplest possible case there is only one time period and the stock price change can be represented by a starting price and two ending prices: like the root, or
node, and the two branches, or leafs, of a very simple tree. We’ll call this a unit tree. However when there is more than one time period the price change process charts out a tree where the leafs of the preceding unit tree are the node of a succeeding one. As the number of time periods increases to infinity the underlying asset can experience any price change within a broad range of numbers with the most likely final figure along the middle values. The visual diagram that represents this behavior is called a binomial event tree.

Figure 3-2: Binomial event tree describing the price change over two time periods of a 10 Gigabyte hard drive. At time zero the price of S—the hard drive— is $100. It can rise 10% or fall 9% \((d=1/u)\) in each time period. It is twice as likely \(-50\%-\) to finish the cycle unchanged, as it is to experience a rise or fall in price \(-25\%\) each.

More generally any diagram that describes discrete possible changes of market variables in discrete units of time is called an event tree and is the first step in solving an options pricing problem by the binomial method. Event trees generally describe the market behavior that is not under the control of the firm. It need not necessarily be binomial, and all branches need not all terminate at the same time period. Its main characteristic should be however that it includes all relevant information pertaining to the underlying asset or cash flow that we wish to study. Thus any structure that has a single starting stock price and that has a finite number of branches that it can reach over a finite number of possible steps is an event tree. In the example figure above we see the price change of a 10 Gigabyte hard drive over a two-month period. The example is modeled as a simple two period binomial tree in which the price of the drive can rise or fall approximately 10% at the end of each of the two periods, resulting in three possible end
prices out of which the middle end price—which corresponds to the beginning price—is twice as likely as either of the other.

One caveat of event trees is the assumption that the progression of the asset market is out of the control of the firm. This is certainly the case for commodity markets, but may not always be the case in subtle ways for technology products. Even so in the technology arena there are many commodity like goods. The dynamic random access memory (or DRAM) and the hard disk drive market used in the example are two of those. Moreover even in the case of more value added products like cutting edge Internet routers consumer demand is largely out the control of the manufacturer and thus assuming that it behaves in a commodity like fashion can only serve as a conservative approximation.

3.3.1.2 The Decision Tree

The next element of the binomial solution process—the decision tree—serves to describe how does management react to the resolution of the uncertainty described in the even tree. Generally decisions are taken only at the resolution of uncertainty points, but often are not taken at all of these points. This is the case because often the end events are the one interest, the time by which the option or options are assumed to expire. Even if it is not the case, by whenever the option has expired, it has achieved a value equal to the difference between the value of the underlying asset and the strike price of the option, or zero which ever is greater.

\[ C^* = \text{MAX}(S^* - K, 0) \]

Equation 3-4: Value of a call at expiry.

"C*" is the numerical value that call options achieve at expiry on the price of the underlying assets "S*". For each terminal leaf of an option C* will usually be different—but may not be—and each of these C*s will be needed to compute the value of the call today "C". With respect to the event tree the only new information we have gained are the C* values, but these are of crucial significance since they embody the decision that management has taken in order to maximize firm value. Thus when this information is added to the event tree previously described we arrive at a new tree we call the decision tree.
Figure 3-3: Elementary decision tree. The values of “S” and both “S*” are known from the event tree. “C*’s are known from having taken the most profitable decision at the end of the relevant period. Another variable “r” the risk less rate is generally always known, thus the only unknown is “C”, which is the value of interest.

With a decision tree completed we have all the relevant underlying asset prices, and terminal leaves option prices, so that with knowledge of the only one more piece –the riskless rate- we have all the information we need to compute the option value $C$.

3.3.1.3 Portfolio Replication

The portfolio replication principle is the third and final piece necessary to compute real options by the binomial method. It states that to find the value of the option we can create a portfolio that produces the exact same payoff at the end of the relevant period as the option itself and compute the value of this portfolio instead. To do this we are allowed to lend and borrow in bonds “B” at the risk less rate “r” and we are allowed to invest in a twin security or stock “S” that has perfect correlation with our option. Thus the one period binomial option pricing method can be stated mathematically in the following formulas:

\[
C^* = f(S^*)
\]
\[
N^*S_u + (1 + r)^* B = C_u
\]
\[
N^*S_d + (1 + r)^* B = C_d
\]
\[
C = N^* S + B
\]

Equations 3-5: The binomial equations that relate the values of a single period call, stock and bond through the law of one price. The first equation indicates that the future value of the call is a function of the future value of the stock, the second and third that the value of the call and the replicating portfolio must be equal on each state of the world, and the fourth gives the value of the call today as a function of the value of the stock and bond today.

The first equation above states that the payoff of the call is a function of the value of the underlying asset at the date of maturity of the option. The second and third enforce the zero arbitrage condition which merely mean that a certain number of stocks “N” and certain number of bonds must equal the payoff of the call at the maturity date in each
possible state of the world. Finally the last equation gives the value of the call today on the basis of the value of the stock and the number of stock and bonds today. The two middle equations can be solved for the variables in the formula for computing the option value of interest into the following two middle equations:

\[ C^* = f(S^*) \]
\[ N = \frac{C_u - C_d}{S_u - S_d} \]
\[ B = \frac{C_u - N * S_u}{1 + r} \]
\[ C = N * S + B \]

Equations 3-6: The binomial formulas to compute the value of a one period call using a replicating portfolio. These equations have been solved for the number of stocks in the replicating portfolio and the value of the bonds in the portfolio today.

These equations now state the number of stocks as a function of the value of the stock and the payoff at maturity, and the number of bonds as a function of the stock up and call up values, the number of stocks and the risk free rate. One key insight from using these intermediates is that we notice that often our net bond position is negative. That is, we are short on bonds. This is the case because to replicate the greater returns of options over stocks we need to borrow money to finance the stock we purchase, thus leveraging our position.

Armed with portfolio replication, we can now use all the pieces we found in the event and decision tree parts of the solution process and compute the value of the option by means of the binomial method.

3.3.1.4 The Binomial Probability Formulas

In essence what portfolio replication states is that all investors act indifferently to risk and will therefore assign a unique value to the same option given fair market prices. Since another way of seeing binomial options is that they are a security whose value is the expected payoff given that there exists two distinct states of the world, the implication is that there exists a precise risk neutral probability “p” and exclusive probability (1-p) that each of this states of the world will occur. And given that both the option payoff and the underlying asset obtain well defined values in exactly these two states it is possible to derive the probabilities from knowledge of current fair price of one or the other. The two equations below describe this relationship.
\[ C = \frac{p_u * C_u + (1 - p_u) * C_d}{1 + r} \]
\[ p_u = \frac{(1 + r) * C - C_d}{C_u - C_d} \]

Equation 3-7: The binomial probability formulas. The first equation states the value of a call as a function of its risk neutral probabilities. The second solves the first for the probability of an upward movement.

There is one particular version of the binomial price movement that is very widely used. In it we strengthen the assumptions that the asset can only make two changes in equal discrete units of time by forcing these changes to be one up and one down and having them be inversely related to each other. In other words that the multiplicative factor of the up movement \( u \) inverted gives rise to that of the down movement \( d = 1/u \). In this case we have more stringently defined binomial probability formulas which are related through these up and down parameters, or a derivative of them that uses a variable we'll call the volatility “\( \sigma \)”. These formulas are often used to model stock and commodity price movements in the financial markets.

\[ u = e^{\sigma}; d = e^{-\sigma} \]
\[ p_u = \frac{e^{r - \sigma} - d}{u - d} \]
\[ q_u = \frac{e^{WACC - \sigma}}{u - d} \]

Equation 3-8: More binomial probability formulas.

It should also be noted that the computed risk neutral probabilities are not the same as the actual observed probabilities. Nevertheless we can arrive at the observed probabilities by inserting the project’s cost of capital in place of the risk free rate while using the same parameters in the rest of the formula.

3.3.2 The Black-Scholes Method

The Black Scholes formula is the preferred method of computing the value of traditional European and American financial options of a single contingent variable since it describes in closed form the price of an option from six fundamental determinants. The formula is nothing other than the result of solving the option partial differential equation subject to the boundary constraint that at the exercise date the price of the option should
be equal to its payoff. The formula is also subject to the law of one price, which says that no investor will pay different amounts of money for two investment opportunities that give right to the same payoffs in the same states of the world.

\[
C = S e^{-\delta t} \{N(d_1)\} - Ke^{-\eta t} \{N(d_2)\}
\]

\[
d_1 = \frac{\ln \left( \frac{s}{x} \right) + (r - \delta + 0.5 \sigma^2)}{\sigma \sqrt{t}}
\]

\[
d_2 = d_1 - \sigma \sqrt{t}
\]

Equation 3-9: The Black Scholes formula for an American call of one contingent variable and with dividends.

Above we have the Black-Scholes price equation for an American call taking into account the value of the option lost to dividends. Some of the parameters are the same as in the binomial model. “C” is the current price of the call, “S” is the current stock –or underlying asset- price, “r” is the risk free rate, “K” is the strike price, “t” is the time to expiry, “\(\sigma\)” is the stock volatility, and “\(\delta\)” are the dividends payed. “\(d_1\)” and “\(d_2\)” are intermediate values that are used to compute the cumulative probability distribution functions \(N(d_1)\) and \(N(d_2)\).

In order to compute a real option value using the Black-Scholes formula we would need to find or estimate all of the six inputs parameters. These parameters are unfamiliar and are quite unlike the sort of numbers we are used to estimating in NPVs or binomial calculations. In some cases, such as the stock/cash-flow volatility it may be impossible to have a good estimate altogether. While it is not the case with options on continuously exchange-traded equity, it certainly is with options on cash flows that may not exist yet or that if they do exist are at best reported every three months. Thus unlike the binomial method the Black-Scholes one may not have much application in most practical valuation situations.

Nevertheless it does have strategic value, precisely because it focuses on the six factors through which managers can influence option value in their companies. With an understanding of the mechanisms by which managers can influence the parameters in the real world, they can enhance the value of the options their firm is holding. We thus proceed to explain the significance and influence of each parameter on option value from a strategic perspective.
3.3.2.1 Risk free interest rate “r”

The risk free interest rate is of special interest from real options point of view because contrary to its impact in NPV calculations –where it enters as an input to cost of capital via the capital asset pricing model or its alternatives- a rise in interests results in a rise in the value of the option.

The logic behind is that a rise in the interest rate deceases the present value of the exercise price of our option. To see how this is the case recall equations 3.6. The middle equation, which is used to compute the magnitude of the number of bonds we need to replicate the option, indicates that the greater the interest rates the lesser the number of bonds. But now recall the bonds are usually part of the replicating portfolio as shorts. Thus the fewer short bonds the lesser will be our debt and the greater will be the value of our call.

The primary lesson is that it may counter to real options logic that prices of uncertain projects or companies should fall when interest rates rise -if everything else is held equal. For managers and investors this may be of significance to their activities in situations where the central bank is aggressively rising interest rates to stave off inflation and seemingly bringing down with its actions the equity prices of growth companies. This is what has happened in the Nasdaq stock market, whose composite index fell from over 5,000 in March 2000 to below 2,300 in January 2001 as the US Federal Reserve raised interest rates from 5.5% to over 6.5%.

Nevertheless it also important to note that options’ value sensitivity to interest rates is among the smallest of all parameters. Thus when such a phenomena as we experienced over the course of the last nine months occurs it may be more appropriate to justify it through other parameters, as we will see below. Moreover the risk free interest rate, although under the control of national central banks, is completely out of the influence of private companies and investors unless they can lobby to influence monetary policy.

3.3.2.2 Value lost over duration of option “δ”

The value lost over the duration of an option is the equivalent to the dividend paid by stock in the case of financial options. It is the value investors loose as claimants of underlying the cash flow due to its distribution to other claimants. In the case of real
options it could be the customers or market share or positioning companies loose to competitors for failing to preempt their entrance, or it could be the maintenance cost needed to incur in order to keep company options open.

The value lost over the duration of an option is a parameter that is not present in any form in NPV models. In binomial models it is present through an adjustment that decreases the price of the stock or cash flow and the call payoff by the amount of the dividend at the payment date. Like the risk free rate of interest its impact on option value is generally small, but unlike it, since dividends represent loses to option holders, a rise in dividends results in a fall in option value.

The presence of dividends losses is one of the reason competing firms often rush to enter new markets rather than wait for the outcome of the contingent event. It may be possible to influence this parameter of real option value by eliminating the dividends losses directly. If a firm manages to contractually lock in key customers, or to impose regulatory constraints on competitors, it may in effect manage the reduction or elimination of its dividend losses.

3.3.2.3 Time to expiry “t”

The time to expiry of a real option corresponds to the exact same parameter in a financial option. It is the amount of time during which the option can be exercised. Like in financial options an increase in the time to expiry will increase the value of the option since it increase flexibility. In fact an option has positive opportunity value because its time to expiry is greater than zero: An option with zero time to expiry has a value equal only to the stock price minus the strike price or zero, which ever is greater.

However unlike in a financial option the time to expiry of a real option is sometimes a fussy concept. It is not so when it is based on some contractual right that a company has acquired from a government, another company or elsewhere. For example company A may grant company B the option to use part of A’s manufacturing capacity between a certain (usually close to present) date and another certain date in the future (of for example five years). In this case the two companies can value the given option as an American call (because it can be exercised at any date before expiry) with a known expiry date. But what would happen if the option in question a company owns is not contractual, but on the other hand is a market option? For example, if a
biopharmaceutical company has an ongoing R&D project that may have useful commercial value until the product becomes obsolete how does the company known when does this obsolescence date occur? The answer is that the project valuators must make an estimate of useful life of the option on a case-by-case and understand that such number is nothing more than a presumably educated estimate.

Of more significance is the fundamental fact that options are contracts that expire. A company that currently enjoys the benefits of owning a growth option can not expect to own it at perpetuity, though in some circumstances it may be the case. For example a company that owns the exclusive rights to some proprietary technology can expect to have the monopolistic right to use this technology to generate revenues only as long as a competitor does not develop a functionally equivalent alternative. If a competitor does develop and alternative, then the option to profit from it may be greatly reduced or even destroyed. Thus companies can increase their value by extending the time to expiry of the options they hold.

Another key fact about time to expiry is that though it has a greater impact on option value than both the interest rate and dividends, it nevertheless is another parameter with relatively little effect on option price.

3.3.2.4 Volatility of expected cash flows “σ”

The volatility of expected cash flows corresponds with the volatility of the stock or commodity price in financial options. Like the time to expiry it is also of fundamental value to the existence of the option. If there were not volatility -the quantification of uncertainty- there would be no value to having the right but not obligation to perform a certain transaction. We would already know how much would the underlying asset be worth by the time to expiry and thus we would know with certitude how much we would need to pay today for the certitude by discounting at the risk less rate. Also like the time to expiry an increase in volatility translates to an increase in option value, but volatility has a bigger impact than “t”.

Nevertheless, even more so that “t”, volatility is perhaps the hardest to estimate of the parameters in a Black-Scholes real options formulation. In the case of financial options volatility is generally computed as a moving average of underlying asset variances or standard deviations from a certain number of most recent periods. Thus for
example the daily price changes of a stock for the past year may be used to estimate its daily volatility as of today. But in the real options world we are generally dealing with a cash flow that is unique, relatively unknown—perhaps without history—and does not trade continuously on any financial market. Thus how to compute its volatility? Just like with time to expiry reasonable estimates can be made by using quarterly cash flow information—or that of shorter times periods if available, using the stock price volatility of single project competitor firms, or using other proxies. Thus for example we may decide that if we are trying to compute the volatility of the free cash flow for a toy internet retailer and we have the volatility for the free cash flow of a book internet retailer then we may use the value of this second as a proxy of the first, perhaps after some adjustment. This adjustment in turn may be estimated by seeing the relative volatilities of the free cash flow for brick and mortar toy retailers versus bookstores.

But we should not forget that it is the strategic understanding what we care about the most. Thus a company that holds real options can enhance their value by increasing the volatility of their expected cash flows. This conclusion, like others before in the real options framework, is at odds with NPV thinking. But we can see how this is clearly the case by going back to Equations 3.6. We note that the number of stocks “N” we need in the replicating portfolio is directly proportional to the difference of the payoff in the case where the stock goes up and the case where it goes down (C_u-C_d).

3.3.2.5 Present value of fixed costs “K”

The present value of the fixed costs of the project is the counter party to the strike price in a financial option. In real terms it represents the incremental capital expenditure that must be incurred in order to gain access to the underlying free cash flow. Thus for example if we have a project where some capital expenditure has already been incurred to purchase the option to further the project, then the second round of capital expenditure that would be required to finalize the project is represented by the present value of the fixed costs. An increase in this parameter decreases the price of the option since more money has to be paid. It tends to have the second largest effect on the price of an option for any given magnitude change of itself.

To compute these costs an estimate must be made at the date of the expenditure and then that value must be discounted back. It is important to note that these fixed costs
are estimates but it is even more important to note that they are expected values that change over time. Even more so, they change not only by the passage of time but by the changing of technology, markets, and even by actions the management of the company can take. It may be the case that the development of a new manufacturing process, or the change in prices of certain raw materials, or other market actions may lower or raise these fixed costs. Thus the primary way of managing the value of company options through managing their strike is to lower the strike price through research and development, developing efficient manufacturing processes, or setting up good distribution networks.

3.3.2.6 Present value of expected cash flows “S”

This component of a real option is the most like its equivalent in a traditional discounted cash flow valuation. It represents an estimate of the cash flow of a project discounted back to the present. It also corresponds to today’s stock or commodity price in the case of financial options. An increase in the value of the expected cash flow results in an increase in the value of a call option on it. Moreover, of all six parameters expected cash flows is the one that has the greatest impact on option value.

From a managerial point of view increasing the expected inflows or decreasing the expected outflows can serve to maximize option value. An important way of doing this is by cascading the investment opportunities that the current option we hold generates by including in its payoff another option. This in effect creates what is called a compound option described below.

The ways a company seeks to maximize the cash flow resulting from its investments includes marketing the product to a larger audience—for example expanding from the home PC business to the corporate sector, or going international. It also includes finding new applications for products the company currently has such as Microsoft’s efforts to universalize windows as an operating system to include servers, palmtops and other types of devices.

3.4 Types of Options by Structure and Application

One of the most important pieces of knowledge we can have for the use of real options is a basic standard set of project options and their combinations that we can identify and match with commonly occurring examples. This can be done since as we have seen earlier from a properties point of view there are only two types of options, calls
of puts, and that each can only be either bought or sold, resulting in only four basic combinations. Nevertheless we rarely observe short real option positions, thus long call and put positions give most of the examples of the use of real options. Moreover the single most common of these combinations is simply going long with a call, which means that once we know its most popular uses we have a very powerful tool. Nevertheless as we will see portfolios of options are common, making this would-have-been simple problem a little more elaborate.

3.4.1 Single Option

The simplest possible project or company to evaluate is that where there is a single time period, a single contingent event, and a single binomial decision based on this event. In this situation management has committed capital at the beginning of the period in order to obtain the right to buy or sell a certain cash flow by committing more capital at the end of the period.

![Figure 3-4: The single real option. This option covers one time period and has only two possible outcomes, thus following the pattern of a unit binomial option. It can be either of a call or a put and it can be used for any of the possible applications described below.](image)

3.4.1.1 Growth, Deferral Expansion, and Extension Options

There are four basic types of single options, as described above in option fundamentals. Having a long call position is the most common of these in the case of both financial and real options and accounts for a majority of the applications in new economy companies. It gives the company the right to acquire a certain cash flow by paying an exercise price at or before the expiry date.

One of the reasons a company may hold call options is that it can give the company the right to pursue a path to growth in the future. Usually these paths to growth
are made possible by technological or marketing investments that result in capital knowledge, positions or networks that only require an incremental investment to give rise to substantial payoffs, thought these payoffs may be highly uncertain. Examples include R&D investments, corporate image marketing campaigns, and even entire technology based startup companies. When the founders of Akamai Technologies chose to invest venture capital in further developing the routing algorithms that are at the center of its services they were investing in the growth option to later capitalize on the gained knowledge to create a useful service that can be sold at a profit.

Growth options need not be internal or supply driven investments. Often companies invest in their customers or suppliers, partners or even competitors in order to acquire an option for growth. Sun Microsystems recently made an investment in Storage Networks in order to capitalize the provider of data storage services so that it could grow and proceed to purchase Sun’s storage systems required for this growth. In doing so Sun was investing in a customer that would grow its revenues potentially much more than its investment had been. Gateway also has invested in its customers by given computer illiterate individuals seminars held at the company’s Country Stores in the use and benefits of computers. Thought the company has branded the seminars as “community service” it is clear they have the potential to increase demand of its products.

Acquisitions in fact can be thought of options for growth. Cisco Systems has put in place one of the best acquisition and integration processes in the whole technology industry. After developing the first Internet router the company has used the cash flow generated by its success to fuel further expansion through acquisitions of new technologies and products that could capitalize of Cisco’s marketing and administrative resources to achieve success. In effect Cisco has outsourced its R&D to the startup market, and has acquired the most promising projects in order to maintain its own growth and the high valuation that goes together with companies heavy in option phase projects.

Another of the uses of long call options positions for companies is in the ability they give to defer further investments. This in a way can be seen as another interpretation of the same growth strategy outlined above. Rather than commit all of the funds necessary to grow today, a company may choose to only invest a part today, enough to create the platform from which a final round of investment might serve to derive the cash
flow. Venture capitalists use this type of option frequently when doing staged investments in startups. By doing so, they irreversibly commit only a minimal part of funds, while waiting for further technological and marketing information that will serve to confirm the profitability of the second investment. The only catch is that VCs often do their investing in more than two stages, resulting in the more complex case of compound/learning options described below.

Expansion options give the holders the ability to increment already existing cash flows by committing further funds to a project. This type of option is often used when a small incremental expenditure serves to complete an extension to a manufacturing plant, or to add a second distribution market to an existing product. An example is the case of plant expansion at RF Micro Devices. The company recently completed a project to create manufacturing capacity for its semiconductors for wireless applications with a second stage project under way, after the revenues of the first part had proven that there exists the necessary demand to justify the expansion.

Extension options are the fourth common use of long real call positions in companies' portfolios. They give their holder the right to extend the use of assets by paying an exercise price. Not so obviously in use by new economy companies, there are often extension clauses in real estate lease contracts that have the economic properties of real call extension options.

3.4.1.2 Exit –or Abandonment-, Contraction, and Shortening Options

Exit, contraction and shortening options are all examples of long put positions in the real options world. An exit option gives its holder the ability to exit a project at or before certain date in the future by paying an exercise price. It is the functional contrary of the growth option and acts as an insurance against market or technological downturns. Such an option can be of great value if a company has committed resources to a certain product or technology that may become obsolete, displaced by a competing technological standard, or pushed out of the market by a competitor's product.

Corning and Qualcomm are two companies that have exercised their exit options in the recent past. The first used to be a diversified industrial manufacturer of glass products, only one few of which were fiber optics and other high tech materials, that divested through sales or closures all of its low growth business in order to concentrate
Qualcomm is a wireless communications company that first exited the cellular handset business, and then the cellular networks infrastructure business (through a sale to former competitor Ericsson) in order to concentrate on the more value added technological standards business (the cellular standard CDMA being Qualcomm's invention). Another company that has exercised an exit option recently was Lucent Technologies, when it sold its power systems division to Tyco International. One thing that is clear is that just as growth options can often be created by an acquisition, exit options can often be exercised by a divesture. Thus there is a half symmetric situation between the creation of calls and the exercise of puts in real options.

Contraction options are the functional contrary of expansion options. They give the holder the right to diminish the scale of a cash flow in the case the economic conditions should dictate that is the more profitable. Contraction options are common within portfolios that contain expansion options. Dell Computer's just in time manufacturing acts like a real time portfolio of expansion and contraction options, constantly adjusting the rate of manufacturing to match the rate of present demand, thus preventing the build up of any inventory and consequently saving company resources. The final type of long put position, shortening options, are the functional contrary of extension options. They give the holder the right to shorten the use of assets by paying an exercise price.

Usually puts will be held in conjunction with the underlying cash flow. That is, nobody will hold real puts "naked", or in other words, with the possibility of exercising the option but not owning the underlying cash flow. Because of this the payoff of the portfolio of interest, the put plus the cash-flow/stock, will be the sum of the payoff of its two components. If we go back to what we learned in option fundamental's we'll remember that this put plus stock combination has a payoff equal in shape to a long call.

3.4.2 Rainbow Options

Rainbow options are really just single options but are characterized by having more than one contingent variable. For example a company may have the option to ramp up manufacturing of a certain product if both the price and the quantity of the product demanded exceed a certain threshold, thus in effect having a rainbow expansion option. This type of options is seen often in commodity markets where the two variables of the
example above -price and quantity- describe all that is to be known about the state of the world.

In new economy companies rainbow options are in less obvious use since in practice the summary variable of interest, total dollar demand, is the result of many input variables besides price and quantity. This is the case because all products are not identical, and competition though intense is not perfect. Moreover from a computational point of view, it is very hard to obtain close form expressions for rainbow options of two or more contingent variables. However computation by the binomial method sidesteps the difficulty of finding closed form expressions for rainbow options, though now the problem becomes constructing a replicating portfolio. Nevertheless rainbow options can be useful in many situations when the company’s options are indeed approximately modeled by the resolution of more than one contingent variable. For example Quantum is a storage devices manufacturer that operates in near commodity markets that must react flexibly to adjust production to the two variables that summarize market conditions.

3.4.3 Compound Options/Learning Options

Compound options are options on options. These are perhaps the most important classes of options because they give the right to further options at the exercise of the current one. In other words the underlying asset of the current option is another option, and may still also includes some cash flow, though not necessarily. Projects and companies that typically can be described by compound options are staged investment start-ups, and infotech and biotech research and development projects. In these the investors choose to allocate a limited amount of funds at each stage and evaluate the project advances at the end of a certain period or pending a certain market or technological test, or clinical trial. The result of these evaluations is what determines if the project or start up goes ahead with more funding or if the investment is terminated at that stage. From an applications point of view these options are often known as learning options. Learning options grant the option holder the right to test market conditions before each successive stage of investment, therefore minimizing the chances of loss.
The compounds option approach is most clearly illustrated by the workings of the venture capital industry. Venture capitalists most often do their investing in usually two or three stages before an initial public offering (IPO). The advantage of this approach is that the investments can proceed incrementally, only if the previous stages have proved promising, therefore limiting the downside potential to investors. Thus a new startup may first receive $1 million in venture funds for research, followed by $5 million to develop a prototype if the research gives positive results, followed by a final $20 million to design for manufacturing and set up an administrative, marketing and sales organization that can distribute the product. In each stage there is the option but not the obligation to invest in the next stage.

In fact the whole process by which many highly successful products in the technological industries have been developed is inspired by compound/learning option principles. Microsoft’s Windows operating system and Intel’s x86/Pentium microprocessor line have evolved through staged investments in each new version of the product. This has forced the changes in design to be evolutionary rather than revolutionary, ensuring backwards compatibility, building on the established platform of applications, peripherals, networks and storage, and thus maximizing and fine tuning the value for customers, the companies and the industry. These staged investments have been in effect compounded call options. It is noteworthy that although Intel had success at each stage of its strategy, Microsoft did not gain any significant market or profit from its first two options—the first two versions of Windows—and nevertheless achieved great profitability and almost total market share with versions 3.0 and later.
3.4.4 Same-Project Option Portfolios

Flexibility –or Switching-, and Scalability Options

Option portfolios arise frequently in real options within certain contexts. For example the single best financial description of many companies’ R&D organizations is that they consist of a portfolio of real options with each option representing a current technology or process under development that may or may not be utilized in further cash flow generating projects. These are an example of multi-project option portfolios, which we’ll study later. There are also portfolios of options on the same project, usually a combination of puts and calls to ensure flexibility or scalability of operations.

The example we gave above of Dell’s just in time manufacturing is a case of scalability option, and in general any portfolio that guarantees the company that holds it the ability to scale up or down in response to market conditions is another. Another example of an option portfolio is an original equipment manufacturer (OEM), such as Cisco, that subcontracts assembling to an electronic manufacturing services (EMS) firm, such as Solectron. Should the OEM have the ability to move its manufacturing to another EMS in case the original were to become uneconomical or face difficulties, the OEM would in effect own flexibility options on its production. We thus see that much of real options portfolios is about hedging.
4 Valuing Projects and Companies using Real Options

In Chapter three we studied the principles of option pricing and real option theory now we must develop and organized framework for valuing projects and companies using real options. We will do this using the old problem solvers approach of divide and conquer. We must divide the real options solution process into several parts, we must divide our understanding of the industry and the company into several parts, we must divide the company itself into several parts, we must compute the values of each part in steps and finally we should bring it all together in the end to review the results by parts and as whole.

Figure 4-1: The process of valuing new economy companies using real options and discounted cash flow methods. The method is based on an analytical strategy where we concentrate in building knowledge of the company by parts and then combining it all together, understanding the result and redoing if necessary.

What follows is a discussion of what we mean by new economy companies, followed by a systematic approach to valuing said companies using a real options framework. The approach contains cautions to avoid common pitfalls, suggestions for visually understanding better the problem, and practical computational techniques to arrive at actual prices. In the next chapter we’ll demonstrate the principles valuing two Internet infrastructure companies: Sycamore Networks and Check Point Software.
4.1 Understanding New Economy Companies

The term “new economy” or its synonyms has been repeatedly used through the history of economic progress. In general every time a technological revolution comes along radically increasing workers productivity, improving the quality of life, and giving birth to new industries dominated by newcomers that command substantial valuations in the financial markets the term has been used. All of us are acquainted with its use in the 1990’s particularly the second half of the decade during which pure play Internet companies began to go public. The first of these was Netscape Communications, went public in 1995, and brought with it a new economic model based on gaining market positioning and becoming the technological standard at the expense of huge loses up front. Its’ stock returns during its first two years were in the hundreds of percent and it quickly commanded valuations that analysts were hard pressed to justify. In fact the company was enjoying the benefits of a market that -despite its somewhat irrational assumptions- was pricing it as a pure growth option with a potentially very high payoff. Many other companies followed.

But as said before we need not look to the last decade for such kind of valuations. In 1901 papers were talking of a “new era” as new technologies and business models were adopted by the economy, high tech new companies and consolidated old ones dominated, and the S&P 500 achieved a local price earnings (P/E) ratio peak of 25. The same happened in 1929, and later the decades of the 50s and 60s brought again economic optimism and high valuations. Thus the “new economy” and the firms that dominate it are only new in a temporary sense. That does not mean that the new economy is not real, just that we must understand what we mean by it.

4.1.1 What we mean by New Economy Companies

We know a new economy company when we see one. It often has had a short life—may be a new IPO or even still venture funded- or has experienced some sort of corporate rebirth—often through acquisitions, divestures, spin-offs or sales- from an old company. It is often small but even if it is not it always is fast growing in revenues and—sometimes- earnings. It commands hard to justify multiples. And it often is the center of media and analysts attention due to its new technologies, marketing strategies or manufacturing processes. In the 1990’s companies in the technology fields dominated the
new economy ranks, but with the wide adoption of the Internet telecommunication and media companies that were essential to its functioning and benefits joined what was understood as the new economy. But as we have seen the new economy companies of the 1990’s were not those of earlier periods, and will almost certainly not be those of future ones either. So what is it that makes a company a new economy company?

Characteristics of the Old and New Economies

Old Economy ← Companies mostly are... → New Economy
Mature Firms ← Startups →

Value mostly in...
Cash Cows ← Growth Opportunities →

Multiples are...
Low ← High →

Figure 4-2: The old and new economies compared.

New economy companies are those whose value is dominated from growth opportunities. As we have seen before growth opportunities generally accrue from the uncertain benefits of today’s investments on the future cash flows of the company. That is, new economy companies originate from highly uncertainty but potentially highly profitable investments of the sort that gave rise to the need for real options theory. Those for which the payoffs could take any number of very different values and for which managerial decision making is crucial to maximizing the worth of the firm. Owning opportunities for growth is the result of the projects the company management has decided to undertake. And as we know most opportunities for growth do not have an infinite lifetime. Thus being a new economy company is not something that is inherent to the firm, nor is entering a new economy something that is a one-time event. It is a state of companies and the economy to which they belong and both companies and the economy can enter and exit new economy phases in their development. Companies are new economy when on the whole they are dominated by growth projects, and the economy is only new when on the whole such companies dominate it. As these projects exit the
growth the phase, which they will by the invariable laws of economics, they will revert to old economy and unless the firms that own them engage in new growth ones the firms as whole will also revert to old status and the economy as a whole will follow suite. We will now proceed to explain more carefully how to determine the new versus old economy status of a firm.

4.1.2 Projects and Project Portfolios

Much of valuation centers on the decision making process of whether to invest in a promising project or not. Real options theory was developed as a method of project valuation, and net present value in fact refers to a method of evaluating projects. Discounted cash flow valuation is an NPV inspired method of pricing the equity of firms. This is fine because in essence firms are portfolios of projects. We can observe this from the fact that some companies are in essence a single project. Often companies get started for the sole purpose of developing and operating a single property, as is the often the case with national infrastructure. Technology startups themselves begin in order to develop a single product or service and market it to consumers or corporations. These startups as they mature add more product lines becoming multi-project companies. On the other end of the spectrum are conglomerates, which are clearly multi-project companies. While conglomerates where in vogue for some decades in the 20th century, it later became apparent that agglomerating very disparate interests did not increase value to shareholders and therefore many undertook a process of project divesture that concentrated the divided entities in certain lines of business.

The implication of this portfolio view of companies is that the some of the consequences of Markowitz portfolio theory hold true not only for financial portfolios but for companies too. The value of companies is simply the sum of the value of its projects when proper care is taken to avoid double and under accounting, the expected return is simply the weighted average of the individual returns of the projects, while the company risk can be found by summing up the entries of the projects’ variance covariance matrix. Further implications is that companies should not be worth more than the sum of their parts unless there are truly some synergies in the merged entity, but that nevertheless a company can reduce the volatility of its expected return by properly diversifying its sources of revenue. Nevertheless it is not clear that shareholders are willing to pay extra
for this diversification that they could achieve at a lower cost themselves directly investing in the financial markets.

\[
CompanyValue = \sum (CashFlowProjects) + \sum (GrowthProjects)
\]

\[
PortfolioReturn = w_a \cdot r_a + w_b \cdot r_b
\]

\[
PortfolioVariance = w_a^2 \cdot \sigma_a^2 + w_b^2 \cdot \sigma_b^2 + (2 \cdot w_a \cdot w_b \cdot \rho_{ab} \cdot \sigma_a \cdot \sigma_b)
\]

Equation 4-1: The value of companies is the sum of the value of its individual cash flow and growth projects. The second and third equations give the portfolio return and variance given expected return and variance of the portfolio's two constituent projects.

A realization of greater significance than this is that not all projects are similar in characteristics and that not all projects are valued by the same methods. Older more deterministic ones are better modeled as a steady stream of cash flows while newer more uncertain ones are better modeled as options for growth. In particular all those businesses that provide cash from operations that grow at a constant rate into the future and that require relatively little investment -or cash cow businesses- are of the first variety, while R&D projects, marketing investments and other kind of uncertain investments with uncertainty payoffs are often the second. The key is to recognize which is which.

Old economy companies as we have described in the previous section will have most or all of their value concentrated in cash flow projects, while new economy ones will have most of their value in growth ones or evenly distributed in a mixture of both. Contrast this with debt and derivatives. Debt traditionally has certain payoffs whose value is straightforwardly calculated from discounted cash flow methods. Derivatives on the other hand are more complex, but equally as pure, instruments that can easily be priced by summing up the value of all the options that constitute them. The issue with new economy equity is that it is not based on clearly certain events or on clearly uncertain ones but rather has elements of both and therefore a dual thinking must be necessary: company equity contains both certain cash flows and uncertain payoffs from options, rather like derivatives contain a sum of uncertain payoffs.
From a practical valuation point of view one of the issues we must carefully encounter is how to separate the cash flows and investments of companies into individual lines of business. In some cases, like when we are valuing startups, we may be valuing in effect a single project company and thus it is easy to assign the cash flows. In some others, like is often the case on the entire cash-flow stage portfolio of companies, separation adds little information at too much cost and is therefore not necessary. Thus in general separation makes most sense in the case of individual growth projects, or even an entire portfolio of them —like when valuing an R&D lab—, and often in those cases companies make some special information available to the public thus facilitating value separation.

4.1.3 Project Life-Cycle and Portfolio Analysis

As we have seen above projects are operations that enterprises undertake and that mature over time. Because the valuation multiples that a project, and the company it forms part of, are influenced by the project’s stage in life, an analysis of the company’s projects lifecycle is an integral part of the valuation process. New economy projects typically begin their life in the R&D lab of an established company or as the only idea that a research or prototype stage startup has. This is typically the stage that represents the creation—or purchase—of the first option for growth in a compound/learning option. At this stage some of the value is recognized, but often the risks are so high that this value does not usually translate into much capitalization. As the technology matures the
product or service goes from R&D, to engineering design, to manufacturing design and each stage representing the exercise of an expiring option and the creation of a new option with greater and greater value.

Once all the technology phase of the project is over and it begins shipping it usually goes through several market expansion options, as new customers are added to the line. Traditional means of doing this is when the product or service is marketed to a new industry, to a new country, or whichever of the personal, small, mid or big business, or institutional sector it had not previously been marketed to. Moreover often products serve as platforms of other products. Thus when Microsoft introduced Windows 3.0 it was creating the option to grow the operating system into wide family of operating environments. Nevertheless eventually all options must take a path to cash flow, at first a rapidly growing one and later a more mature one. At this stage the method of valuation changes as real options becomes less appropriate than discounted cash flow.

![Figure 4-4: The life cycle of new economy funds.](image)

The flow of funds in the new economy begins when investors originally purchase the equity of companies that have nothing but project ideas. These investors are in fact capitalist entrepreneures who take very large risks for the promise of uncertain but potentially very large payoffs. Thus these investors in fact purchase growth options. These new economy companies research and develop products and services that may turn out to be profitable when sold to their customers. When this happens the project matures and become a cash flow project -at least in part since further customers and derivative products can be gained from it. Eventually however the project matures completely but
probably by then the company will have used the proceeds from cash flow to invest in new growth options. If the haven’t they could use the cash flow to pay dividends to their stockholders and truly become an old economy company. If they have they will need to keep investing back the proceeds from the new projects themselves as they mature to sustain their existence as growing entities. Another alternative is to sell the cash flows and use the proceeds to purchase new growth options and sustain their high valuation.

Any individual company can move its projects from old to new economy back and forth by means of skillful management. Corning went from an old economy glass manufacturer to leading supplier of fiber optic cable for the bandwidth explosion. It shed many of its old units and used the proceeds to acquire growth options. Cisco System’s skillful maintenance on the top league of growth companies has rested on its ability to use its steady stream of cash flows to finance the acquisitions of new growth options. These options it exercises and uses their cash flows to finance more acquisitions. PC manufacturers like Dell on the other hand have experienced an exercising of their options with no meaningful new ones being acquired, and hence a fall in their relative valuations. It is arguable that eventually scale presents a problem to any company, as options large enough to surpass the value of the steady stream of cash flows become scarce.

This is difficulty in trying to maintain a position as a new economy company is compounded by the fact because most options have a finite life. Nevertheless there are a few options that do conserve their value close to forever, as long as skillful management keeps them active. Very strong brands are some of these, as companies like Disney can use their name to facilitate the introduction of many new media content products. The investments the company continuously makes on the Disney name ensure that the option -or a portfolio of options that resemble a single perennial one- always exists, and that only incremental investment is needed on individual products to create consumer awareness.

4.2 Understand the Company: What does it do?

Now that we’ve explained the basic principles necessary to understand new economy companies’ valuation from a real options perspective we must learn how to implement the method. The first step in such process is to understand the company, what role it plays in the economy, its history and its intended future.
4.2.1 What lines of businesses is it engaged in?

The first step in valuing a new economy company is determining in what lines of business the company is engaged in. First we determine if it is a product, a service or a combination company. If it has products we determine if there are hardware, software, or technology –ideas such as patent rights- products or some combination of them. If services we determine if it has consulting services, utility like services (such as providing communication lines), or others. No less important is the fact that we must determine if the company is primarily a manufacturer, a marketer or an R&D lab, among other possibilities. This last distinction is of crucial significance because on it will be based the focus we will later grant its various productive assets. Even in the case that the company is primarily a hardware product manufacturer for example we have to clearly determine what products does it sell.

Thus for example if we were to define the business of Dell Computer we will have to specify it is a personal computer manufacturer and marketer, with presence in the desktop, laptop, server, workstation and storage markets. In other words we will have to specify its segment information. Companies’ annual reports, 10-K forms, and IPO prospectus are the first source of this information, but many other sources are available. Fundamentally the question we are trying to ask is: “What projects does the company engage in?” That is, we are trying to determine the composition of its project portfolio as it stands today.

4.2.2 How did it get there?

After we have determined the company’s project portfolio we must determine what path did the company take to reach its current state. In other words we must determine its historical project evolution. If the company has been established for many years chances are this path is long and complicated, but as we have seen above this company will most likely be an old economy company and therefore this kind of analysis will probably supply less useful information, will thus be less necessary and therefore can be done in less detail. Most high tech companies that we know today are at most two decades old (from the beginning of the PC boom), and many are younger than five years (the Internet’s commercial birth). Among exceptions one notorious one is IBM, but many of the ongoing projects of this company are clearly in cash flow stage, although
nevertheless it has plenty of growth opportunities in its labs. The primary value of this kind of historical analysis is that it allows us to determine in what stage are the company’s projects -which we determined previously- currently in, and it gives us hints as to where does the management of the company intend it to go next.

Going back to our Dell Computer example the company was founded as a desktop PC manufacturer, but later used its options for growth to enter the notebook, server and workstation markets and later the storage market. It has most of the time remained a direct seller, but after being a direct telephone and face-to-face marketer it added the World Wide Web as a channel. It also originated as a US company that first expanded to the UK, and continued adding served countries as it matured with most of its efforts centering this days on the Asian growth markets: China, and South East Asia.

4.2.3 Where does it intend to go?

The most important reason why we need to know how did it evolve into its present day form is to be able to determine where it may go in the future. It is in the future of the company that most of its value is present, especially if it is a new economy company. Most of the value will be in the form of growth options for which we must determine what is their objective (what cash flow do they intend to secure), and how (what is the uncertain factor that must be determined) and by when will this objective be obtained. We’ll discuss the last two more carefully in the next sections.

Management plans and strategies are the most important source of future growth opportunities for companies. In general it is the company executives who must be open to, and even pursue the opportunities that the market will present them. In this sense it is much about vision. Nobody, not even the company’s management, knows what the future will bring, but the management must be able to see that unexploited opportunities exists, must position the company to take advantage of these opportunities, and must execute their strategy when the future clarifies there are profits to be made from them. In other words, management must engage in real options thinking. It is therefore valuators job to enter management’s minds and build this options strategy into the model. This task can be facilitated by disclosure and communication, but can also be derived by modeling management’s strategic thinking from economic principles and the company’s style.
As a matter of example it is known thus that many PC and server manufacturers, such as Dell, Sun Microsystems and Compaq, are aggressively pursuing the storage market. They already own market shares from which they derive cash flows, but doubtlessly in their minds most of their value in the segment rests on the options for further penetration. EMC Corp., the actual leader in the field with a 35% market share, is in fact pursuing its own growth strategy by emphasizing its storage management software products. In a different field Internet portal Yahoo! Inc. has recently commenced a strategy of diversifying its revenue stream away from advertising by charging fees for its online sales and auctions, and may soon add other services to its revenue generating pool. It was in fact these options that gave Yahoo! its large market capitalization –which topped $100 billion-, before investors’ change of perception of the company’s future cut it down to a more modest $25 billion today.

4.2.4 What does/did the path depend on?

Once we have determined the objectives the company is pursuing we must identify on what event outside of the control of the company –or partially under its control- do the attainment of these objectives dependent on. Often these events are the presence of certain market conditions, which in a practical sense mean the existence of demand. Nevertheless this demand is often dependent on the penetration of complementary products or services, the purchasing power of the customers, and other factors that we must determine. Building all of these into the options model would be a hassle, and would result in rainbow options that would not be easy to value. Therefore we model their effects by stating that a certain potential demand or revenue \( S_u \) may materialize for which the option has a certain payoff \( C_u \), and that the demand \( S_u \) is the result of all the conditions that we have determined.

As an example of this we notice that Yahoo! Inc., the leading Web portal company, would not have achieved its status had Netscape Communications (now part of AOL) not developed and popularized Web browsing technology, had AOL and other Internet service providers not popularized connections to the World Wide Web, and had US Robotics (now part of 3Com) and other modem companies not delivered connection speeds of at least 56Kbits/sec to most households, to a name a few.
4.2.5 When do/did those events happen?

Just as it is important to determine what impacts management’s decision to pursue certain paths it is important to determine when the decision itself is taken. In the world of real options there is not hard expiry date, as it is the case in financial options, but nevertheless there is a relatively fixed length period of time over which financial markets revalue companies if they determine that said companies have missed growth opportunities. Thus an approximate expiration date does exist. We use this approximation, which we derive from study and educated assumptions, to put a precise date on the expiration of real options, but we must recognize that these dates are flexible. All possibilities have to be analyzed and the most likely one chosen but allowed margins of error of several months -about a quarter is right-, and nevertheless we must continuously assess our model as the future plays out.

Suppose that Juniper Networks is developing a new high-end router for the Internet backbone service provider market. Juniper has determined it will require two years to arrive at a commercial product from its current research prototype, and that at the end of those two years it may be able to sell the product at a profit. Nevertheless the company also knows that Cisco Systems is developing a competing router and that if its own is not available in at most two and a half years then Cisco’s will be, and it will conquer the niche. Thus there are two companies competing for the same cash flow and only the one that exercises first its growth option will be able to secure the profits. Thus the true expiration date of each option is the exercise date of the other option, which will probably be no earlier than in two years and no later than in two and a half. Nevertheless if neither company exercises, both options may well expire worthless since in four years both products would have been rendered obsolete. Also, if a new paradigm renders both products obsolete before the two years, it would imply that the true expiration date has been foreshortened further.

4.2.6 Sketch an evolutionary tree for the company

An evolutionary tree summarizes all the information and insight we have developed over our study. Depending on how old a company is we may begin the tree with incorporation and/or the initial public offering, carefully analyzing what was the company trying to achieve at the outset and whether it is still pursuing the same goals.
We should include information on product launches, advances on research projects, customer acquisitions, corporate acquisitions and divestures and other company events that have the power to impact value by determining the outcome of option events, creating options, divesting options, or acquiring or selling cash flows. An evolutionary tree should flow in time but it is not necessary that it should be so precise so as to prevent some overlaps in the time axis where they are imprecise. An evolutionary tree can also serve to emphasize the relative importance of various projects by making some more clearly visible or central than others. Of importance in drawing an evolutionary tree is recognizing that the company may have reinvented itself entirely along the way by shedding most of its old units and acquiring plenty of new ones. As discussed before, this has been the case of several large technology companies such as Corning and EMC Corp.

Figure 4-5: Juniper Networks evolutionary tree from inception to December 31, 1999. Product launches have been assigned to boxes, Semiconductor and board manufacturing agreements have been assigned to the time axis and customer acquisitions come after the products they have purchased. Significant corporate events, such as the company's initial public offering, are also included.

Above we include one example of an evolutionary tree. Juniper Networks is a young company and therefore its history is simple. Nevertheless by drawing its diagram we intuitively arrive at some of the assumptions that will allows us to do the real options valuation. We can see how many customers it has and when did it gain them. We see what products lines it has to offer and how it may expand them. We also recognize that like many young electronic developers and marketers Juniper out-sources most of its
manufacturing. We can foresee that Juniper will incur low fixed costs of goods sold and a variable cost of sold that is proportionate to volume. We can guess which customers it will acquire, or which customer that it already does business with will buy a new product, and other such insight and information.

4.3 Structure the Problem

Use the Binomial and Discounted Cash Flow Methods

In the first part of the solution process we concentrated in understanding the portfolio structure of the company. We determined in what projects is the company currently engaged in, and whether those are cash flow projects or option projects. The next step is to value each project separately according to its type.

For cash flow projects we should use traditional discounted cash flow/NPV methods. Thus we must make projections for cash inflows and outflows several years into the future, we must estimate the cost of capital associated with the projects using CAPM, the three factor model or some other suitable alternative and we must discount back to the present the value of the project. It is outside the scope of this paper to give a detailed description of this process. Nevertheless the process must be carried out carefully especially to ensure that there is no double or under accounting of revenues or expenses in the whole company valuation. A way to guarantee this condition is to base the whole valuation on a DCF model and only add option values to account for special investment projects that would otherwise simply be expensed. Alternatively option values can be computed as the centerpiece of the valuation model and DCF analysis can be added to round up all parameters that have been left out. Below is a more detailed description on how to value the option parts of the company.

4.3.1 Model the Uncertainty: Draw an Event Tree

By analyzing the company we derived an evolutionary tree that charts in broad terms the progress of all individual projects over their lifetime. Now we must extract from this evolutionary tree that focuses on the whole company the knowledge and assumptions that pertains to each individual project and round out in greater detail the market information that is necessary to have completed event trees. To achieve this result we go back to the first question we asked when setting up the problem, and ask again if
these lines of business correspond to actual distinct projects, and if so we search for the answer to the third question to see if these distinct projects are best modeled by options or cash flows. If they are modeled by options then it is best to draw event trees for them. The necessary additional information can be found by looking at the answers of succeeding questions such as what does the event depend on, and by when is the resolution expected.

What we really seek are demand numbers that will indicate the maximum potential revenues the company may enjoy. How to arrive at these demand numbers, and what is relevant to them is something that is very company specific, but in most cases can be though of as a simple multiple of the number of goods that can be sold, and the price for which they can be sold, not unlike the top line of a forecast income statement. This is the constructive approach –that which begins by the smallest unit and builds up. Another way to arrive at the demand numbers is to determine what could be the total market size of the product and extracting the fraction of the market that the company hopes to secure. Moreover both approaches are compatible because we may have determined the total market size through a forecast of total number of units multiplied by an average selling price.

In particular cases we can arrive at such demand estimates quite easily by looking for the costs up the supply chain. Thus for example research studies concentrating on consumer purchases of cellular handsets give us the total market size that a company in the industry, such as Nokia, will encounter. Similarly a company that sells power amplifiers to Nokia and other handset manufacturers, such as RF Micro Devices, can derive their total market size by taking the fraction of handset makers’ costs of goods sold that corresponds to their products. Many other sources of forecast market information exist -especially in the highest growth areas such as wireless and storage- that can be consulted for estimates.

In general determination of these numbers is not unlike the determination of revenues in a DCF model. Nevertheless there is one important difference with respect to DCF models; while in DCF models we seek to estimate the single most likely outcome of events, in real options event trees we seek to establish at least two but possibly more probable outcomes. How do we determine these alternate values? Like in DCF models

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one approach is to assume a proxy high rate of growth path and a proxy low rate of growth—or even contraction—based on percentages. We could assume that in a one period growth option project the revenues may grow either 100% or 50%, each representing one path of the event tree. These numbers in fact may not represent the actual most likely path, which may be in between both—say 70% growth—but there rests the key. Our thoughts must be reoriented from the most likely event—the median—to two or more events that weighted by their probabilities will give the expected outcome—the mean.

4.3.2 Model Managerial Flexibility: Draw a Decision Tree

Once we have determined and described the sources of market uncertainty we must also determine and describe what would be the optimal decisions management will take in each uncertainty resolution state. In essence the process consists of determining what will the payoff to the company be if the management exercise or not at each point and choosing the most profitable—or least costly—alternative. For this we must know the strike price—or fixed costs—of the option, the marginal costs—which can be modeled in a fashion similar to fractional ownership—and any other possible peculiarity the payoff diagram may have in each situation. In subchapter 3.2 we showed the basic payoff structure of a long call and other option positions, but although this model may have the virtues of simplicity without loosing focus on the two main traits of any payoff—a fixed and a variable cost—any forced application of this exact model may result in results that are not meaningful. Thus we must always apply models with our particular problem in mind.

For example, we may have a company that may have product for which it is responsible from a design and marketing point of view, but which it may not manufacture internally for competitive reasons. Many electronic circuits and devices startup companies will often fall in this category, since they may not have the resources to build and maintain large expensive printed board or semiconductor plants. Thus the company will probably choose to subcontract the manufacturing to an electronic manufacturing service company such as Solectron Corp. or Jabil Circuit, or perhaps a large hardware company with spare capacity such IBM. But such a subcontractor will charge its services in a fashion that is likely to benefit large orders over small orders, probably charging less per unit for large orders. As an example, semiconductor manufacturers charge original
equipment manufacturers less for orders over 1,000 units. Thus kinks could be introduced in the payoff function, increasing the number of pieces in the diagram from two to potentially many more. And this information is needed in order to determine the payoff instances of each leaf in the decision tree.

Once we have the event tree and the payoff diagram we can proceed to combine the information contained in the two to determine the right managerial decision and the benefits that such a decision will accrue to the company. In the case where we had two terminal leaves in a one period tree we must find the market point of each terminal event in the payoff diagram on the stock axis, read all the information pertaining fixed costs, variable costs and any special items, and then write down the payoff as determined in each leaf on the decision tree.

4.3.3 Estimating the Real Options Payoff

One of the issues of doing real option valuation is that we must be careful to deal with cash numbers. When we value financial options we deal with cash investments, cash strike prices and cash payoffs necessary for or resulting from the position. Nevertheless much of the data that we have available for estimating the value of real options comes from company financial statements, which are prepared to comply with standard accrual accounting rules such as those outlined by the FASB in the Generally Accepted Financial Principles (GAAP). These indicate that accrual devices such as depreciation, amortization and depletion are to be used to spread capital expenditures over the revenue period, that research and development and sales and marketing costs are to be expensed as incurred, and that in general capital expenditures are treated should be treated as expenses to be accrued in a period that matches the revenues they generate, or that they are to be expensed immediately if the revenue is uncertain.

This makes sense for accounting purposes but it does not for real options valuation. First because real options valuation, just like NPV, must be cash based: the cost of items must be recorded when they are paid, which may or may not be when they match the revenues they generates. But perhaps most importantly because these costs are not really seen as expenses to be distributed over time, but as one off investments that may result in increased revenues in the future. This is the foundation of real options theory. While in GAAP based DCF valuations we seek to compute net income by
expensing all costs that are to result in uncertain payoffs as they are incurred, in real options we seek to see such cost as investments on real options that may provide benefits or not.

4.3.3.1 How to Account Depreciation, Amortization and Depletion

Whenever a company is involved in the purchase of a new manufacturing plant, it is generally committed to pay for each stage as its contractors complete it. Nevertheless for accounting purposes generally the same plant will be expensed over its useful life, which does not coincide with its completion, and could last several decades. If we are to do a real options model of a planned plant expansion we must avoid the GAAP approach to capital expenditure and use a completion approach instead.

Typically a company that commissions new infrastructure will pay for the project in installments. The first of these may well be options to actually pursue the building of the plant, or if not may be down payments for initiation of the project. Whatever they may be the first round of payments will in fact represent the price paid to purchase the option to build the plant. Subsequent payments will in turn represent the exercise of the option or the chain of compound options. Each of these payments should be expensed immediately, in the sense that they should be interpreted as one off investments. The payoffs will appear at each exercise as they occur and thus will in a sense be expensed immediately too. They key is that cash transactions are matched through the execution of the entire option rather than by revenue and expense matching.

4.3.3.2 How to Account Operating Expenses

Research and development, sales and marketing and other traditionally recurring expenses in accounting statements most also be rethought in light of the real options approach to valuation. One of the observations that led to the development of real option theory was that R&D investments, which are highly uncertain in their payoff, must often be expensed without being able to properly forecast or measure the benefits that the investments will accrue. It was also observed that this approach underestimates the value of these investments to the firm. Thus it was observed that the GAAP approach to this kind of expensing and its impact on perceived company value, as well NPV’s own difficulties, were among the leading indicators of the need for a real options approach to uncertain investments.
In a real options framework we seek to establish such expenses as investments in the future growth of the company. R&D projects, engineering design, and other accumulation of technical know how become option purchase—or creation—operations whenever they can be properly identified with a potential payoff no matter how unlikely. Similarly marketing and some sales cost, which result in potentially increased future benefits due to brand awareness, distribution networks, or market positioning must also been seen as options for growth.

To see why this approach to uncertain but nevertheless capital building investments is justified we need not see further than the way startup technology companies allocate their resources during their early stages of development. Often these companies commit substantial resources to building their organizations, particularly their product portfolio, sales organizations and their administrative bureaucracy. Sycamore Networks a marketer of optical networks products spent more than their revenues during their first full fiscal year (1999) on operating expenses. The company had revenues of $11 million, out of which $8 million represented the cost of revenues. This allowed them to earn a gross profit of about $3 million. Nevertheless they incurred expenses of $14 million in R&D, $4 million in sales and marketing, and $1.5 million in general and administrative, clearly sending their net income negative. The reason Sycamore operated in such a fashion was because such expenses represented a building of non tangible assets: technical, sales and administrative know how that have value. But these assets are in fact larger than what a company of Sycamore’s current size based on its revenues needs. Thus in effect these expenses represent investments that will allow the company to pursue increased cash flows in the future. In a real options framework these costs will indeed be expensed immediately but the difference is that it will be stated that they represent the purchase of an option to certain cash flows in the future, as it should be.

With this new view on operating expenses it will possible to value early stages startups more accurately, and see none COGS expenses for what they are: investments necessary to earn cash flows on the companies’ products. This does not mean that all operating expenses now become investments, since many will accrue no benefit. But it does mean that we should look carefully to what is behind them and especially in the case
where they seemingly overwhelm the gross profit look out if these expenses represent actual commitments to future growth on the part of the management.

4.3.4 Compute and Understand the Real Option Value

Once we have arrived at a decision tree in the binomial solution process the next step is to set up a portfolio composed of some cash flow and bonds that replicates the desired payoff. This step is mostly mechanic but can be tricky if we are not careful. Generally we will use the revenues of the company as the cash flow itself, just as we use the underlying common stock when we value equity options. After all the only security that will change together with the payoff in the exact same states of the world is the project revenue. Our bonds will simply be dollar value securities that pay the risk free rate of interest on whatever time basis our option uses, which most of the time will be yearly.

Below are equations for the value of a call. These equations are equivalent to the binomial equations in chapter 3, but have been solved to specify the value of a call in a single mathematical expression -without recourse to intermediate values such as the number of stocks or bonds in the portfolio- as a function of our replicating portfolio parameters.

\[
C = \frac{S_u - S_d}{S_u - S_d} \times S + \frac{C_u - C_d}{S_u - S_d} \times S_u
\]

\[
C = \left( S - \frac{S_u}{1 + r} \right) \times \left( \frac{C_u - C_d}{S_u - S_d} \right) + \frac{C_u}{1 + r}
\]

Equation 4-2: Equations for the value of a one period binomial call option given a replicating portfolio with underlying stock S and risk free rate r. The second equation allows altering the value of the option as a function of the current stock price S, the values of the stock and call in case of up and down movements \(S_u, S_d, C_u, C_d\), and the risk free rate r.

By observing these equations we realize that the value of a call option is directly proportional to the value of the underlying cash flow and its own payoff in the case of an upward movement of the stock. Less clearly seen from the equations is that the value of the call increases with the value of its downward movement payoff. This can understood intuitively however because in either case when one of the payoff rises and the other remains constant the call can be worth no less: it just increases our expected payoff no
matter what the outcome is. As either the value of the stock up or stock down parameters increase the value of the option falls however. Mathematically this is so because less of the stock will be needed to replicate the option payoff.

![Chart of percent change in value of a call as described by the equations above for any given percent change in its stock, stock-up, stock-down, call-up, and call-down parameters. The original parameters in this example are $100, 200, 50, 100, and 25 respectively. Notice that the current value of the stock has the greatest impact, but that the change in the upward payoff is the second greatest.](chart)

Above we have a chart of the change of value of an option relative to a change in value in each of its parameters based on the call equations at the beginning of this section. Our example describes a situation where the cash flow is currently worth $100, may halve or double in value over one time period, and where the payoff from the call will be 50% of the revenues in either outcome. We notice, as expected, that the present value of the stock has the greatest impact on the price of the call. Other than the risk free rate of interest -which is not plotted- the changes in either the stock down or the payoff down parameters have the least impact. This is so because they are worth the smaller part of the option. Remember that the option is valuable because it allows us to profit from the upside without loosing out on the downside. In this example we have a situation were in essence we have two strikes that allow us to profit from two outcomes. And the lesser one is the one that is responsible for the less value. Nevertheless one general lesson to be taken from this example is that sensitivity analysis -using with charts like the one above-
on our parameters is crucial to understanding what real option values inform and how are they impacted by different assumptions.

Now let's make some simplifying assumptions to the equations. Assume that the call is worthless in the case that the price of the underlying asset or revenue decreases. This allows us to eliminate the value of the call in the case of a stock fall. If we then go back to the statement that the value of a call is a function of the value of the underlying asset, and in particular enforce that its value is equal to the gross margin we can extract from the cash flow minus the strike price of the call, where both the margin and the strike price are known parameters, then we simplify the equation further because we have eliminated the value of the call in the case of a rise in the underlying cash flow. Thus all we need to determine are possible values for the underlying cash flow in the future, the possibly value of the fixed costs to be exercised and to look up the risk free interest rate. This problem in fact has almost been reduced to the level of complexity of a standard discounted cash flow problem, but with the advantage that we deal with capital investments and gross margins in a real options context.

\[
C = \left( S - \frac{S_a}{(1 + r)} \right) \cdot \left( \frac{\text{Margin} \cdot S_a - K}{S_u - S_d} \right) + \frac{\text{Margin} \cdot S_u - K}{(1 + r)}
\]

Equation 4-3: This is the same as the second equation 4-2 with the value of the call equal to zero in the down scenario and equal to the (gross) margin times the stock up minus the strike in the case of an up scenario. This situation is probably the single most common for all real option values.

In the figure below we show the value of the call described by the equation above when we let the variable and fixed costs vary. This has important implications as it explains why two companies – for example a hardware and a software one – which have identical underlying cash flows but different payoffs show different multiples in the marketplace. Such could be the case of Microsoft and Intel, as we have described in previous sections.
Figure 4-7: Value of a call as we vary the fixed “K” and variables cost “(1-Margin)” in the equations above. The other parameters are stock up at 200, stock at 100, stock down at 50, and the risk free rate at 5%.

For mathematical completeness we can now transform the last equation to include the up “u” and down “d” parameters or the volatility parameter “σ” that we use in the context of financial options, and rewrite the equations below. From these equations it would be possible to derive a chart that plots the call value C as a function of volatility. Nevertheless the volatility parameter and its proxies are rarely used directly in company valuation because by basing ourselves in volatility we constrain our freedom in determining stock changes and payoffs flexibly. Moreover for financial options a price versus volatility chart is available in many options textbooks. From these equations it is just important to understand that price is a positive function of volatility, as we have said before.

\[
C = \left( \frac{S - u*S}{(1+r)} \right) \left( \frac{Margin \cdot (u*S) - K}{(u-d)*S} \right) + \left( \frac{Margin \cdot (u*S) - K}{(1+r)} \right)
\]

\[
C = \left( \frac{S - e^{\sigma*S}}{(1+r)} \right) \left( \frac{Margin \cdot (e^{\sigma*S}) - K}{(e^\sigma - e^{-\sigma})*S} \right) + \left( \frac{Margin \cdot (e^{\sigma*S}) - K}{(1+r)} \right)
\]

Equation 4-4: Equations relating the value of a call to the value the underlying cash flow given an upwards movement of “u” and a downwards movement “d”, or a symmetrical upward and downwards movement with volatility “σ”. Notice call value increases with volatility, margin and current cash flow value while it decreases with strike price. This is a one period option.
One other particular context of importance in binomial valuation is compound options. This type of options are one of the most frequently used in valuing new economy companies because all company projects are in a sense the outcome of previous projects. Knowledge has accumulated and this knowledge has acted as invested capital in the pursuit of new projects. What we must guard from when dealing with compound options is that the value deriving from imbedded options must be included in the payoff of the first one. That is, the prices of successive options are included with the cash flow minus the strike at the terminal period of the first option. Second we must ensure that the present value of the stock at period zero includes the cash flow derived from successive periods. But this would be the case if we have derived our event tree properly. Finally the value of the stock has to match at the instant where both options exist. That is elementary bookkeeping.

4.4 Sum the Values and Analyze the Company

Once we have computed and analyzed the value of each individual project we must study the value of the company as a whole, as we study a portfolio of equities or cash flows. One key distinction we must quickly make is what is the aggregate value of option and cash flow projects relative to each other to understand whether the company truly is a new or old economy one. Any company whose value is more than 50% derived from growth opportunities probably deserves to be called new economy whatever its industry is. Looking at the aggregate option versus cash flow values also serves to visualize how much of the capitalization is at risk in case of an unfavorable turn of events in the future. It also serves to explain valuation multiples as a company consistent of mostly growth options will not have the cash flows to justify its valuation on that basis. Also we should know if one single project, or a small group of project, account for most of the value whatever they might be. We could further see if the company's options for growth derive from developments in its R&D labs, or from the potential to acquire new customers. Pie charts will generally allow us to intuitively understand percentages while mounted bar charts will allow us to grasp absolute values in addition to relative ones. Other visualization aids should be used to emphasize further important points.
4.5 Review and Redesign if Necessary

4.5.1 Compare the Real Options Value with a DCF One

Comparing the real option value we have computed with the value given by the discounted cash flow method is more than just a mechanism to check the integrity of our model, it is also a way of determining the option content of the company. It is because of the potential to shed light on both of these issues that we often do a DCF model and compute its value to complement our real options model. One way to go ahead is to collapse the real options model into a DCF one. We probably already have a set of projects being valued by the NPV method. Thus it rests just to collapse the option projects into NPV ones, by assuming certainty in the outcomes and no managerial flexibility, and adding all of their values. This of course defeats the point of why we valued these projects via the real options method in the first place: because they were project with considerable future uncertainty. But we must always remember that if we choose to do this DCF check it is just to shed some further led into the company and our valuation methodology and not because we believe it is the better method.

4.5.2 Compare the Computed Values with the Market Capitalization

One of the key methods to determine if our valuation process has been successful is to compare our result to what the financial markets believe the company should be worth. By comparing our computed value with the market capitalization we should be able to assess within a reasonable discrepancy if we have included all relevant factors and if our assumptions have been reasonable. It is unlikely that the market will be terribly wrong in its assessment; although it may well be that this is the case. In fact we may be trying to prove that the market is mispricing the company, in which case we are by definition doubting our check, nevertheless the comparison can always shed important criticism.

Except in the case of believed extreme market mispricing our computed value should certainly not be discrepant from the market value by more than an order of magnitude, and more stringently by more than 50%. In particular we should ask ourselves if we have made too optimistic or pessimistic assumptions, or more fundamentally if our model is faulty, should we notice that our result gives too large or small a value relative
to the market. Is there anything that the market knows that we don’t? Is there anything we
know that the market does not? Is the market currently gripped by short-term panic or
euphoria? All of these are important review questions.

We can increase the reliability of this assessment by looking at other companies
in the same industry as the one we are currently analyzing and also by looking at the
same company at a different period of time. The first comparison will allow us to see if
the general sentiment relative to this particular company is good or bad relative to its
competitors, and if so we must determine why. It may indicate an expectation that the
company will take or lose the market lead in fashion that is likely to affect its value. Are
these expectations consistent with our model’s views and if not can we argue against
them?

Similarly when doing a comparison against past values of the company we must
determine if enough has changed in the economic prospects to merit the price change. If
their has been no price change for much time then we must determine if our estimated
price is consistent with the market price, and if not we must determine if we have a good
reason to defend our view of the value of the company. It is important to remember that
comparison with market values does not give the answer of whether we have properly
modeled the company or not, just like comparison with an NPV model does not. We
engaged in real options valuation because we thought that both could be wrong. But it
does add some rigor since we will be forced to defend our view against another
alternative.

4.5.3 In Case of Discrepancies Look at the Following

If by any of the review methods above or other insights we recognize that the
result of the process does not seem to assign the correct value to the company, then we
should try to locate the error that lead to the problem. This may involve more than one
issue and if it is the case it will take more than one correction for the model to give the
right value. We should go about it by tackling the more suspect issues first, one at a time,
in order to see which are the minimal corrections that give the result that is closest to the
intended. Then we may correct a few issues at a time and stop when we believe we have
achieved the best model and it is proved by a value we consider appropriate.
4.5.3.1 Check for double and under accounting.

The first step in locating a potential error is merely checking if the books balance. In particular we want to make sure that the cash inflows and outflows that the company reported for the current and past periods add up to their reported values. To do this we must remember to include all the information we have built into our model when doing the addition. Broadly speaking the company should have the exact—or at least the approximate—net cash flow for the periods we are studying as reported on financial statements. Nevertheless we must remember that when doing our real options modeling the emphasis is on company insight, and not necessarily on accounting accuracy, and therefore we can not be too stringent with this requirement.

Should we find any discrepancy there are at least two fundamental reasons why they may have arisen. One is that we did not incorporate certain items that we should have. Another is that we could have incorporated certain items twice, by assigning them to different projects. In either case the model has to be redesigned, and care should be taken of quick fixes that may result in an economically faulty setup.

4.5.3.2 Has any project been overlooked or confused?

Another potential source of errors is overlooking certain lines of business in the company, especially if they are small or uncertain yet, and are therefore not clearly visible to valuators. Just as likely is that a project that may have been valued as a cash flow might really be an option, or vice versa. For example a company’s research lab may be secret and it may contain very valuable ideas that the market as a whole knows about or assumes correctly and that individual valuators are bound to miss. But often the sources of such errors are not as undercover as the last example suggests and merely are the result of simplistic or incorrect models.

For example it is conceivable that a valuator trying to arrive at correct market price for EMC Corp., the storage company, may concentrate on the storage systems business and overlook the faster growing but somewhat smaller storage management software business. Both will probably qualify as growth option businesses but the second is clearly the one that experiences the greater level of cash flow volatility and uncertainty. That implies that a model that emphasizes the management software part would result in a greater computed value.
4.5.3.3 Are the DCF projections and WACC reasonable?

These are questions that are to be asked of any DCF model. In case of valuation problems we first ask if our cash flow projections are reasonable, and then we ask if the cost of capital we have used to discount them is realistic. Of these two often the discount rate is the more controversial issue, though many valuators hotly debate each others’ cash flow projections. The issue with the discount rate is that some valuators, such as venture capitalists, are prone to exceedingly high rates in order to compensate the bias that the other side –often the entrepreneurs who produced the cash flow forecasts- themselves introduce. In the financial community discount rates used for new economy companies vary from 12% to 60%. In the long run few people think that 60% is a realistic cost of capital but it is indeed the case that a privileged few new economy companies –such as Dell Computer during the 90s- have achieved compounded rates of return in excess of 100%; but these are the exceptions that confirm the rule that over the long run rates of return much above the long term market average -between 10% and 15% depending on the starting year and the index used- are unreasonable. Thus use of very high discount rates will significantly decrease company value when it is less appropriate to do so, since most uncertain project will have been be valued as options.

On the issue of cash flow projections it is a matter of judgment, but just like in the case of the discount rate if it is necessary to assume a very high rate of growth then the project might have been better valued as an option project. Certainly any cash flow that increases at a rate greater than 30% is better valued as an option, but even so most traditional old economy companies will not have cash rates of growth greater than 10%. Thus care must be taken that if the assumed rate of growth is too high, then the project is more an option than a cash flow. One such example is Gap Stores Inc., a specialty retailer that for much of its history achieved revenues growth above the 20% mark. Yet much of this growth came from new stores sales –the exercising of growth options- as old stores usually achieved rates of growth no larger than 10%. Though the company could well have been completely valued as a cash flow company, it is clear that its growth came from the exercising of its options.
4.5.3.4 Are the option payoffs and asset value accurate?

Just like in valuing cash flow projects estimates could be in error, it is possible that the assumptions that go into the determination of option project parameters may be faulty. When this is the case option values will be out of line and thus the company value will be too. One of the most likely ways this could happen is if the payoffs of the project have been either under or over estimated. If this is the case we should determine whether we have properly projected the future value of the underlying cash flow. For example, if we are estimating the value of Unix server and workstation manufacturer Sun Microsystems we may wish to know whether we have properly projected the rate of growth of one of its product lines. If we are trying to project servers and we have assumed that they grow in revenues—in the upwards path— at 10% a year a look at what is happening in this market well tell us that we have underestimated the parameter. Conversely if we assumed 200% growth in the upward path, maybe our views are too optimistic. The other parts that go into the determination of the payoff are no less important: these are the various costs associated with the product. An assumption that Sun enjoys 80% gross margins in servers is unrealistic given that such products are manufactured goods. If still we have doubts over our payoffs maybe our model is at fault. An option can well deviate from the standard strike plus fraction type we described previously and we should be open to such issues.

The other critical parameter in the real options solution process is the present value of the cash flows. This is not just the cash we can take out from the project today, but all the cash we derive from it at all periods of time into the future discounted to the present. For traded equity this is just the price of the stock. For projects of more than one period that matter is more complicated. In the case of an option of a single branch we have to discount all the cash flow payoffs at the risk free rate back to the present to arrive at $S$. In the case of an option with multiple branches we have to do the same but weighting the value of each branch by their risk neutral probabilities as determined by the binomial formulas. We can do this by using the binomial probability formulas given in the previous chapter. Given the importance of the current value of the asset in option price determination, care must be exercised with this issue.
4.5.4 Redesign if necessary but remember the 80/20 rule

It is important to remember if redesigning our model that simplicity is key to
insight. Complicated models will add little information to the picture and will cloud the
sources of value in the company. In many scientific disciplines, including valuation, there
is the well-known rule that we can capture 80% of the realism with only 20% of the
detail. It is at this balance that we seek to arrive.

For example it may be the case that refining the portfolio to include more
individual projects that currently sit rolled up within others will serve to alter the value of
the company by 5%. In the case of new economy companies 5% is too small a valuation
difference to merit the extra hassle. The value of established technology, Internet, and
other new economy companies can typically fall and rise by 5% during a typical trading
day. Higher growth ones with more uncertain futures can easily do so by 10% or more.
Thus this level of detail is not merited if that is the only change we will have. On the
other hand remodeling is sometimes more about understanding than it is about value. If a
systems company has products in the hardware and software sectors it may make sense to
split these two in order to understand better the company, whether the change will result
in an altered value or not. As we have mentioned before this could be the case of EMC
Corp., whose storage management software group is of strategic importance beyond its
cash flow value. But notice that this strategic value can be understood, and in fact is, a
value that is reflected as an option potential.
5 Two Examples of Valuing Internet Infrastructure Companies

5.1 Sycamore Networks

5.1.1 Understanding the Optical Networks Company

Sycamore Networks is a manufacturer of software based optical networks equipment for the network service providers markets. Its hardware and software products allow their clients to easily meet the demand for high speed data services over their fiber optic networks by easing transition from old to new technologies, providing scalability, interoperability and intelligent systems that reduce the costs of deployment, maintenance and upgrading. In particular Sycamore’s products allow network operators to eliminate certain legacy hardware –such as SONET/SDH equipment- and to avoid altogether the conversion of optical signals back to electrical signals once they are on the optical networks for purposes such as routing. In today’s environment of rapid change and progress in the optical data networks markets –that drive the Internet and other data networks- these products are very valuable.

Sycamore was founded in February 17, 1998 and since it has been developing its hardware and software products, and building its administrative and sales organizations. In May 1999, during the last quarter of its first full fiscal year, it begin shipping its first completed product, the SN 6000 Optical Transport Product, to its first customer: Williams Communications. In its second full fiscal year the company added eight new customers, including both US and international network operators such as Storm Telecommunications Limited, Enron Broadband Services, and 360 Networks Inc. It also expanded its commercialized products to include the SN 8000 Add/Drop Product, the 16000 Switch, and the SILVX Network Management Software. Moreover the SN 8000 was upgraded during the year to support new requirements and technologies such as Gigabit Ethernet and the ability to operate 1600 Km without electrical regeneration. The company also acquired Sirocco Systems during the fourth quarter of fiscal 2000 to add its network edge optical switching product. The company has added employees, numbering 800 by the end of fiscal 2000, expanding R&D, sales and support, marketing and others.
It also expanded its manufacturing agreements with Celestica—which covers all current products—and Jabil Circuit—that covers some products under development.

Figure 5-1: A schematic product-centered evolutionary tree of Sycamore Networks. IPO occurred on October 27, 1999. This was shortly before the launch of SILVX Manager. Thanks to the IPO and other financing activities the company had 1.5 billion dollars in cash as of 31st of July 2000. From a customer perspective a single client accounted for 100% and 92% of revenues in each full fiscal year.

The company intends to continue to focus in its current four lines of business (transport, add/drop, switching and management products), but intends to add solutions to be able to cover the network end-to-end. In particular the company intends to capitalize on the service providers desire to achieve better network topologies, higher wave counts, longer transmission distances, and higher speeds, all with the pure optical equipment the company supplies. Thus it intends to continue to improve the performance of their current products. Other elements of their growth strategy include working with their customers to generate demand for high speed data services, continue to utilize a software based architecture, buy off the shelf components for their products whenever available, and continue to outsource their manufacturing. The software-based architecture comes as part of the effort to supply their customers with just in time solutions. Furthermore the company intends to capitalize on their industry experience and connections to achieve their goals. The vision of the company is to be to be the leading supplier of intelligent optical networks management hardware and software worldwide. The company will successfully capitalize on this vision if they continue to hold the technological lead and can successfully acquire and retain new customers.
5.1.2 Structuring its Product Portfolio

Sycamore has four main product lines. The division of these lines has been designed so that the company is able to cover all important segments in the optical networks infrastructure marketplace.

5.1.2.1 The SN 6000

The SN 6000 is the transport product in the company’s range of offerings. It allows its users to work within their existing (old technology) SONET/SDH networks thus facilitating the migration to the new technologies developed by Sycamore. This is the company’s first introduced product. From May 1999 to July 31st 1999 of their first full fiscal year all $11 million was derived from it and just one customer: Williams Communications. The COGS for the year where of $8,486 thousands, but that includes set up fixed costs that would not be repeated in the future. Thus 75% percent of revenue where gone in costs.

5.1.2.2 The SN 8000

The SN 8000 add/drop product is a complete stand alone optical networks solution. It can be used in ring or point-to-point configurations and for access, interoffice, regional or backbone networks. Like the SN 6000 it can be overlaid on existing networks to ease the migration for customers. This product was already introduced in the 1999 fiscal year but did not count significantly for revenues until the fiscal year 2000.

5.1.2.3 SILVX

SILVX provides optical network management capabilities through the SILVXSource and the SILVXManager products. SILVXSource is designed to run on the Sycamore’s SN line of appliances while SILVXManager runs on centralized management server stations. The line simplifies configuration, provisioning and management of networks by automating many labor-intensive processes with software. SILVX products are targeted at broadband and virtual private networks markets.

5.1.2.4 SN 16000

The SN 16000 is Sycamore’s optical routing offering and potentially one of the most profitable products of the lineup. The product was introduced in June 2000. The product provides the end-to-end wavelength switching and routing — up to know
unavailable by any vendor— that is necessary to cost effectively build the mesh topologies present in today’s networks with older technology.

5.1.3 Understanding where its value comes from

We choose to model Sycamore Networks using a real options structure that is inspired in traditional DCF analysis. We use a five period compound option that assumes that the company tends to follow an upward path to profitability and therefore presumes we need only to focus on that path. Lower branches in the tree—which represent decreases in revenues from the previous quarter—terminate rather than branching further, as it would be the case if the company were to exit the business after the given period. This serves us a reminder that the life of Internet infrastructure companies at this early stage is precarious, and allows us to simplify the model.

![Figure 5-2: Schematic of the event and decision trees used to value Sycamore Networks. The first period corresponds to end of the year 2000—where we presumably stand. Projections are done for full fiscal years 2001, 2002, 2003, 2004 and 2005.](image)

In the upper path we assume a rate of growth of 200%, 150%, 100%, 75% and 50% for the underlying revenue of Sycamore in each successive year. We believe this is possible given its current rate of growth, the fact that it substantially has only one costumer, and that some of its products have not derived revenue yet. This leaves the company with nearly 8 billion in yearly revenues by 2005. This is a large optimistic number, given that Cisco Systems’ 2000 revenues were of 12 billion dollars and Cisco is the largest data-networking vendor in the world. Nevertheless it is possible and we will assume this best-case scenario.

In computing the real options value we used a replicating portfolio consisting of each years revenues and payoffs. To simplify the calculation we assumed that each years revenue, payoff and options could be computed independently and discounted back to the present at the risk free rate, rather than compounding the total value of the company down to the first option. The implicit assumption is that the company will follow the
upper path of growth even though at each point it may exit, and therefore that we can split the company by yearly projects rather than by product-line projects. One consequence is that we can compare the value of the company year wise with the DCF value. Another is that should the company fail to follow the upper path we know that all successive years growth and their values will be cut out of the market price and substituted by the worth of whatever other unknown branch it follows.

Figure 5-3: Value that is derived from each year in the company's model according to the DCF and real option models. Notice that in the real options model more value is given to the future growth opportunities than in the DCF model. Also notice that in the DCF model there is some negative value assigned to the first period due to heavy investments relative to payoff.

We have further assumed that the company gets more efficient in its operations and investments as it matures, therefore expending less as a fraction of revenues in COGS, R&D, sales and marketing, and property. We have based the forecast of these expenses on industry standards—as determined by Cisco Systems and other Internet infrastructure companies—while remembering that Sycamore is a company with certain strategic traits such as strong commitments to research and outsourced manufacturing. The trade off between such forces—as high R&D investment and low manufacturing expenses—determine its free cash flow. We have assumed away corrections due to
changes in working asset and liabilities. Also for simplicity and given that it is almost entirely true we have assumed the company has no meaningful debt.

Our real options model gives us a value of over $10 billion for Sycamore Networks given our company assumptions and a risk free rate of 5%. By contrast the DCF model we computed gives us a value of $6 billion when using a cost of capital of 17% (this number was determined following the example of Morgan Stanley’s Internet equity research group). One thing that is important to understand is that these models are highly sensitive to the assumptions made. Increasing revenues forecast by several dozen percent each year and decreasing the operating expenses and investments of the company by 5% of revenue increased value in the real options model up to $15 billion. Clearly those are the two parts of the model that are driving value. Should the company be able to gain new customers and diversify by means of R&D and acquisitions fast enough it will be able to demonstrate the $8 billion worth that the market is currently assigning it. Given that in 2000 its value peaked at $50 billion it would seem to be a bargain. Nevertheless we are inclined to believe it is closer to fair price now given our assumptions and therefore would issue a cautious buy at $8 billions or less in market value (approximately a price of $30 a share or lower).

5.1.4 Reviewing the Model

In our model we have made many simplifying assumptions in order to be able to have an intuitive picture of the company. It would be more economically correct to draw a more exhaustive event tree that would include more possible states of the world, including both more optimistic and pessimistic scenarios. At this stage Sycamore is a company that experiences great volatility in its revenue base and as such could be worth more than what our current model suggests. Nevertheless such a model would require however a way to automate the determination of management decisions (ie investments) at each point in time to make it tractable, or alternatively it could simplify the decisions from complex accounting based ones to simpler financial options inspired ones. Another issue with the model is that the terminal value of the company weights heavily and it is the most uncertain of parameters. A change in the year six value of the terminal cash flow by a billion impacts the company worth by almost half a billion. Under this conditions estimated value could be held hostage by the terminal value.
We have already compared the company’s DCF, option and market value and said that our real options value seems reasonable in that light and seems to indicate a positive investment opportunity. This seems to confirm the reasonableness of our computations. Nevertheless one key assumption that may improve the result if removed is that each option can be valued almost independently, sparing us from having to discount the present value of the company’s revenues back to the present to determine a single $S$. Having to discount $S$ using DCF techniques would in some ways defeat the point of the real options process: avoiding the pitfalls of DCF. But nevertheless in some circumstances it may necessary to seek support in the technique. DCF can not be entirely avoided and even in a real options context it must be used as part of the model.

5.2 Check Point Software Technologies Inc.

5.2.1 Understanding the Security Software Company

Check Point Software Technologies is the worldwide leader in security software for the Internet and private networks. Its main two product lines, Firewall-1 and VPN-1, allow companies, governments and institutions to have presence in the Internet and other networks while reducing the risks of intrusion, snooping and other security breaches that
are generally made easier by network connections. The company also develops and markets network software that provide performance and availability services, such as their leading FloodGate-I bandwidth management solution, and network management, such as Provider-1 and Meta IP. The company's success rests on its Stateful Inspection network security technology standard, which allows users to experience greater performance, scalability and the ability to add new applications much more efficiently than with older architectures. It also has leading technology in network queuing, and IP address mapping. All of these products are immensely valuable in the Internet economy, where e-commerce, supply chain management, and other network applications increasingly require greater, but more secure network connections with other parties and the outside world.

Check Point Software Technologies was established in Israel in 1993. Its first product was the Firewall-1, which was introduced in April 1994, and for which revenues were recognized in the third fiscal quarter of 1994. Since, the company has expanded the Firewall-1 family of products and added the VPN-1 family. Most of its $425 million in revenues still derives from its two main product lines. Most of its original revenue generated from corporate clients but the service provider market has experienced faster growth and may thus make most of the revenues in the future.

The company intends to continue its strategy of being the leader in network security software by pursuing four main strategies. It intends to remain an easy supplier of software and hardware product, by keeping simple its product offerings and distribution methods and pricing schedules. It intends to aid the establishment of the Open Platform for Security (OPSEC) standard established by the company in 1996. Check Point also intends to extend its comprehensive end-to-end security solutions portfolio to cover all elements of the network. Finally they intend to further their sales reach, as they have done by expanding in Europe, Latin America and Asia. Check Point’s Strategy is thus primarily to stay focused in retaining and expanding its market leader role in security for the Internet. In this role it competes against many Internet related companies, including some much larger corporations such as Cisco Systems, but Check Point’s superior products and range of offerings should allow them to keep the lead.
5.2.2 Structuring its Product Portfolio

5.2.2.1 Security

Firewall-1 is a security suite that integrates access control, authentication, encryption, network address translation, content security and auditing. This product line gives the company 32% of the worldwide firewall market making it the clear leader in the field. Other than the flagship Firewall-1 based on the company’s Stateful Inspection technology, other security products are Firewall-1 SecureServer –a cost effective solution for single servers running critical applications-, Multigate –which provides enterprises and service providers point-of-presence based security-, and Check Point RealSecure –a real time attack recognition and response system. Substantially more than half the company’s revenues have derived from Firewall-1 sales.

5.2.2.2 Virtual Private Networks

VPN-1 allows companies, their customers, suppliers and other related parties to establish their own secure virtual private networks (VPN), distinct from the Internet, while protecting their resources and information in a similar way to that done on Internet with Firewall-1. The entire line includes VPN-1 Appliance Family, VPN-1 Gateway, VPN-1 SecureClient, VPN-1 SecuRemote, and VPN-1 SecureServer. The functions of this line of products include protecting servers, clients, remote connections and other network parts from eavesdropping, data tampering and other intrusions. Most of the non Firewall-1 revenues of Check Point derive from the VPN-1 family.

5.2.2.3 Network Performance and Availability

Performance products include FloodGate-1, which provides convenient data traffic management to avoid congestion on Internet and Intranet links. ConnectControl enables other Check Point Software to balance the connection load among several available servers. VPN-1 Accelerator Card is a hardware based product that improves VPN performance by accelerating encryption.

5.2.2.4 Network Management

The company also includes several network management solutions that facilitate the task of administrators in monitoring, assigning, and upgrading system resources. Provider-1 allows (Internet and other) service providers and large enterprises to centrally
monitor and assign security policies or corporate sites while providing isolation between customer databases. Meta IP allows automated IP addressing and naming. It uses Check Point proprietary User-to-Address Mapping (UAM) technology. Other management software produced by the company includes Account Management Module, Open Security Extension, Reporting Module, and VPN-1 Certificate Manager.

5.2.3 Understanding where its value comes from

For Check Point we used the same tree structure we used for Sycamore Networks, but updated the parameters to match the software company. The table that describes Check Point's valuation process is at the back in the appendix. One of the key advantages of Check Point is that the company enjoys a very low cost structure. Part of this comes from being a software rather than hardware manufacturer, which decreases the variable costs of the company. While Sycamore was constrained to variable costs of between 55% and 30% of revenues (at 50% representing ownership of only half an option), Check Point had gross margins of up to 92% or variable costs of just 8%. In the bottom line its margins are of around 50% after expenses, which consist mostly of sales and R&D.

![Bar chart]

Figure 5-5: Relative gross profits and cost of revenues of both Check Point business lines and Sycamore in thousand of dollars. The total height of each bar represents total revenues for the given company in the given year.
In fact one of the more rapidly expanding business segments of the company is its services group which due to personnel costs has a higher cost of revenue than software manufacturing. Nevertheless this group still accounts for the smaller part of its revenues and as such for simplicity and lack of precise segment data we have joined it together with the product segment as a whole. Having been founded in 1994 Check Point is a midsize and maturing software firm. As such we have projected slower revenues growth than for Sycamore. Its sequential year-to-year growth on the upper path of the tree should be 100%, 90%, 80%, 75% and 70% in each of 2001 through 2005. On the lower branches we have also assumed it is less likely to loose revenue by only allowing falls of 10%, 8%, 5%, 3%, and 2%. This assumptions are justified on the basis that the need for security solutions is sure to grow as VPN’s and e-commerce applications gain prominence, that Check Point is the established leader in security software for the Internet, and that in particular it already commands a substantial share of the firewall market.

![Figure 5-6: Value that is derived from each year in the company’s model in thousands of dollars according to the DCF and real option models. Notice that in the real options model more value is given to the future growth opportunities than in the DCF model.](image)

With the assumptions described above the real option value of the company is approximately $17 billion. This compares with a DCF value of $13.5 billion. Like with Sycamore much of its value is weighted towards later years. We believe the company will continue to perform well, but in one particular line it will loose some of its financial
appeal. The company currently enjoys a tax break from the government of Israel designed to encourage high tech companies to establish themselves in the country. That translates into the company having an effective tax rate of between 3% and 6%, mostly due to the tax liabilities of its American subsidiary. With the expiry of the last elements of the break by 2005 the cash flow the company generates will decrease. Because of all the reasons above we do not recommend to buy, though current owners of the shares should hold. We would buy at market caps of $15 billion or below.

5.2.4 Reviewing the Model

In studying whether our model successfully describes the value of the firm we go back to the financial markets for guidance. Currently being worth more than $20 billion the company seems to be overvalued in the markets or undervalue by our model. Given the already optimistic assumptions in the model we are inclined to believe it is overvalued in the markets.

![Check Point Software's DCF, real option and market values](image)

Figure 5-7: Check Point Software’s DCF, real option and market values in thousands. Model assumptions include a 17% WACC and a 5% risk free rate. The data seems to suggest that Check Point Software is currently overvalued but given the price volatility of the stock it is very close to fair value.

To support this view we notice that Check Point, unlike Sycamore, is currently trading close to all time highs. The company has not suffered the deep corrections that other sectors in Internet infrastructure have. Only storage leaders such as EMC Corp.
may be holding their market value better than Check Point. And therefore we believe the company will either experience a correction or have zero returns for the foreseeable future.

Changes that could be done on the model to improve its insight is to split the company into its product and service operations. The product operation will still command higher multiples, but higher growth at services, which could equal products in several years, may serve to explain a higher value. On the down side the phasing out of the tax breaks may work to reduce the cash flow available to the company. Factoring other liabilities such as accrued severance payments (required by Israeli law) will further reduce the value of the company. Also like in the case of Sycamore much of the value is assigned to the terminal year, which may need refinement. Currently it is assumed to be a multiple of the previous year revenue or cash flow, but a growing annuity followed by a slower growing perpetuity might be more realistic.
6 Conclusion and a Look into the Future

In this paper we have discussed some, but by no means all, of the most important issues in applying real options theory from both a theoretical and practical point of view to valuing and understanding new economy companies. As is fundamental to any option problem we have discussed the importance, value and impact of future uncertainty and managerial flexibility in dealing with it. Because of that it becomes even more evident that managerial skill is of fundamental value in technology and other high growth companies. A manager that does not know how to envision and prepare for the future will miss many golden opportunities that his rivals will surely take. It is in fact probably because of this that so many companies exist in new industries, so that the chances that some will achieve the goal are increased. It would be very interesting to pursue this line of study further to develop an understanding of how much value does a manager truly bring to a company, whether that has to do with the uncertainty he encounters and the flexibility that he must muster, and whether that serves to justify some of the more extreme compensation packages among new economy firms.

A point of more practical than theoretical interest is to extensively study compound binomial real options. These, in essence, are the workhorses of company real options valuation and as such a good understanding and a developed framework can make a large difference between meaningful results and none. Compound options are fundamental to companies because everything a company does has impact on the future opportunities that will be available to it. They also provide the practical bridge necessary to unite DCF valuation and strategy, as they allow following courses of action or evolution and measuring the impact they have on company value. Until a few complex systems of binomial compound options have been understood and thrown into user-friendly frameworks universal application of real option theory will remain limited to a few practitioners. Another area of real options theory that will require further study in order to truly allow practical use of the theory is how to numerically and yet intuitively deal portfolios of options, especially compound options as described above.

Visualization has important applications in real options and any sort of company analysis. By means of visual diagrams we are able to understand and communicate better what are the important characteristics of the company under question. By means of visual
diagrams we can study the evolution of companies, their product markets, their customer markets, and their future plans. We can also grasp better what is their worth and how is their value dependent on the outcome of future events. Financial markets value companies based on the available information and valuator’s assumptions and expectations. As such, changes in expectations and assumptions can cause large changes in the prices of companies’ equity and understanding the risk in this is an important use visualization. Thus visualization can and should be extended to be able to grasp at a glance how much are companies worth, and how much would they be worth if our model assumptions changed instantaneously.

In the end, all of what we have mentioned above are tools or ideas. What we really want the most is to put them to practical use. One such potential use, just as I have intended to illustrate by example, is in equity research and valuation as done by financial analysts. In terms of absolute output to society it is just as valuable that more analysts should learn and use real options techniques than it is that researchers continue to develop the theory in all its mathematical grandeur. If real options were better known by practitioners it would come less as a surprise the seemingly irrational market behaviors that have characterized the recent past, less money would be lost, and more profits would be made. The investment management community will be better able to grasp the value of technology companies, and they would be able to deliver better results to investors in a less volatile market place. In a way this paper was a marketing campaign on the democratization of real options, but more work remains to be done.

The other area where real options theory has the greatest potential is in entrepreneurship. Real options bridges the divide between the unknown and value, and in the process allows us to better grasp the principles of entrepreneurship and innovation. Value is created when uncertainties are resolved. Aspiring entrepreneurs and innovators and their financial backers now have the tools to tackle their planning and decision process. But just like in the investment community more democratization of the theory has to be done in R&D labs, startup ventures, venture capital firms and other entrepreneurial organizations. Innovation is the precursor of wealth and through real options we can think better about how to innovate.
7 Appendices
### Sycamore Networks' Real Options Value

**Fiscal years ends July 31st**

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<th>1999</th>
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<td>297,000</td>
<td>668,250</td>
<td>1,188,000</td>
<td>1,819,125</td>
<td>2,338,875</td>
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<tr>
<td>Percent of $</td>
<td>74%</td>
<td>53%</td>
<td>50%</td>
<td>45%</td>
<td>40%</td>
<td>35%</td>
<td>30%</td>
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</tr>
<tr>
<td>Gross Profit</td>
<td>2,800</td>
<td>93,000</td>
<td>297,000</td>
<td>816,750</td>
<td>1,782,000</td>
<td>3,378,375</td>
<td>5,457,375</td>
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<tr>
<td>Percent Margin</td>
<td>26%</td>
<td>47%</td>
<td>50%</td>
<td>55%</td>
<td>60%</td>
<td>65%</td>
<td>70%</td>
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</tr>
<tr>
<td><strong>&quot;Down&quot; Payoff</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable Cost Percent of $</td>
<td>50%</td>
<td>45%</td>
<td>40%</td>
<td>35%</td>
<td>30%</td>
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</tr>
<tr>
<td>Gross Profit</td>
<td>59,400</td>
<td>187,110</td>
<td>475,200</td>
<td>883,575</td>
<td>1,169,435</td>
<td>1,403,325</td>
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<td></td>
</tr>
<tr>
<td>Investments</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Research &amp; Development</td>
<td>14,000</td>
<td>54,000</td>
<td>148,500</td>
<td>326,700</td>
<td>564,300</td>
<td>883,575</td>
<td>1,169,435</td>
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<tr>
<td>Percent of $</td>
<td>124%</td>
<td>27%</td>
<td>25%</td>
<td>22%</td>
<td>19%</td>
<td>17%</td>
<td>15%</td>
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</tr>
<tr>
<td>Sales and Marketing</td>
<td>4,000</td>
<td>30,000</td>
<td>89,100</td>
<td>222,750</td>
<td>445,500</td>
<td>779,625</td>
<td>1,169,435</td>
<td></td>
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<tr>
<td>Percent of $</td>
<td>35%</td>
<td>15%</td>
<td>15%</td>
<td>15%</td>
<td>15%</td>
<td>15%</td>
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</tr>
<tr>
<td>General and Administrative</td>
<td>1,400</td>
<td>6,700</td>
<td>17,820</td>
<td>44,550</td>
<td>89,100</td>
<td>155,925</td>
<td>233,888</td>
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<tr>
<td>Percent of $</td>
<td>12%</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
<td></td>
</tr>
<tr>
<td>Total Value of Operating Investments</td>
<td>19,400</td>
<td>90,700</td>
<td>255,420</td>
<td>594,000</td>
<td>1,098,800</td>
<td>1,819,125</td>
<td>2,572,763</td>
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<td>46%</td>
<td>43%</td>
<td>40%</td>
<td>37%</td>
<td>35%</td>
<td>33%</td>
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</tr>
<tr>
<td>Total Percent of Operating Expenses</td>
<td>246%</td>
<td>90%</td>
<td>93%</td>
<td>85%</td>
<td>77%</td>
<td>70%</td>
<td>63%</td>
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<tr>
<td>Purchases of Property, Plant &amp; Equip.</td>
<td>5,700</td>
<td>41,000</td>
<td>89,100</td>
<td>148,500</td>
<td>148,500</td>
<td>259,875</td>
<td>389,813</td>
<td></td>
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<tr>
<td>Percent of $</td>
<td>50%</td>
<td>21%</td>
<td>15%</td>
<td>10%</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>Total Value of Investments</td>
<td>25,100</td>
<td>131,700</td>
<td>344,520</td>
<td>742,500</td>
<td>1,247,400</td>
<td>2,079,000</td>
<td>2,662,575</td>
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</tr>
</tbody>
</table>

**Net "Up" Cash Flow (Payoff-Investment)**

-38,700 -47,520 74,250 534,600 1,298,375 2,494,800 10,000,000

**Present value discounted at:**

17% 40,615 54,241 333,758 693,412 1,137,906 3,898,386

**Discounted Cash Flow Value:** $6,077,117

**Value of each years' C' discounted at:**

5% 98,255 340,350 954,169 2,052,433 3,551,447 3,898,386

**Real Options Value:** $10,895,041

**Market Value:** $8,000,000 As of February 2, 2001
Check Point Software Technologies' Real Options Value  

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<thead>
<tr>
<th>Fiscal Years Ends December 31st</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Items</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>Terminal</th>
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<tbody>
<tr>
<td><strong>S_u</strong></td>
<td>219,000</td>
<td>425,000</td>
<td>850,000</td>
<td>1,615,000</td>
<td>2,907,000</td>
<td>5,087,250</td>
<td>8,648,325</td>
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<tr>
<td>Growth Rate</td>
<td>100%</td>
<td>90%</td>
<td>80%</td>
<td>75%</td>
<td>70%</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>S_d</strong></td>
<td>382,500</td>
<td>782,000</td>
<td>1,534,250</td>
<td>2,819,790</td>
<td>4,985,505</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Growth Rate</td>
<td>-10%</td>
<td>-8%</td>
<td>-5%</td>
<td>-3%</td>
<td>-2%</td>
<td></td>
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</table>

**"Up" Payoff**

<table>
<thead>
<tr>
<th>Fixed Cost</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable Cost</td>
<td>22,000</td>
<td>35,000</td>
<td>68,000</td>
<td>129,200</td>
<td>232,560</td>
<td>406,980</td>
<td>691,866</td>
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</tr>
<tr>
<td>Percent of S</td>
<td>10%</td>
<td>8%</td>
<td>8%</td>
<td>8%</td>
<td>8%</td>
<td>8%</td>
<td>8%</td>
<td></td>
</tr>
<tr>
<td>Gross Profit</td>
<td>197,000</td>
<td>390,000</td>
<td>782,000</td>
<td>1,485,800</td>
<td>2,674,440</td>
<td>4,660,270</td>
<td>7,956,459</td>
<td></td>
</tr>
<tr>
<td>Percent Margin</td>
<td>90%</td>
<td>92%</td>
<td>92%</td>
<td>92%</td>
<td>92%</td>
<td>92%</td>
<td>92%</td>
<td></td>
</tr>
</tbody>
</table>

**"Down" Payoff**

| Variable Cost Percent of S     | 50%  | 45%  | 40%  | 35%  | 30%  |      |      |          |
| Gross Profit                   |      |      |      |      |      |      |      |          |

**Investments**

| Research & Development         | 20,000 | 30,000 | 85,000 | 161,500 | 290,700 | 508,725 | 864,833 |
| Percent of S                   | 9%    | 7%    | 10%   | 10%    | 10%    | 10%    | 10%    |
| Sales and Marketing            | 70,000 | 110,000 | 212,500 | 403,750 | 581,400 | 1,017,450 | 1,729,665 |
| Percent of S                   | 32%   | 26%   | 25%   | 25%    | 20%    | 20%    | 20%    |
| General and Administrative     | 13,000 | 20,000 | 34,000 | 64,600 | 87,210 | 152,618 | 259,460 |
| Percent of S                   | 6%    | 5%    | 4%    | 4%     | 3%     | 3%     | 3%     |
| Total Value of Operating Investments | 103,000 | 160,000 | 331,500 | 629,850 | 959,310 | 1,678,793 | 2,853,947 |
| Percent of S                   | 47%   | 38%   | 39%   | 39%    | 33%    | 33%    | 33%    |
| Total Percent of Operating Expenses | 57%    | 46%    | 47%    | 47%    | 41%    | 41%    | 41%    |
| Purchases of Property, Plant & Equip. | 6,000    | 41,000    | 25,500    | 48,450    | 87,210    | 152,618    | 259,460    |
| Percent of S                   | 3%    | 10%   | 3%    | 3%     | 3%     | 3%     | 3%     |
| Total Value of Investments     | 109,000 | 201,000 | 357,000 | 678,300 | 1,046,520 | 1,831,410 | 3,113,367 |

**Net "Up" Cash Flow (Payoff - Investment)**

| Present value discounted at:   | 17%   | 17%   | 17%   | 17%   | 17%   | 17%   | 17%   |
| Discounted Cash Flow Value      | $13,495,804 |      |      |      |      |      |      |
| Value of each years' C' using:  | 5%    | 5%    | 5%    | 5%    | 5%    | 5%    | 5%    |
| Real Options Value              | $17,271,231 |      |      |      |      |      |      |
| Market Value                    | $22,000,000 |      |      |      |      |      |      |
| As of February 2, 2001          |        |      |      |      |      |      |      |
8 References