Valuation of Technology Using "Real Options"

F. Peter Boer

OVERVIEW: *Cash flow models for valuing technology are increasingly out of touch with market-place valuations. While investor psychology and perceptions about the future may drive the marketplace, the theory of real options can go a long way toward closing the valuation gap. More importantly, it is a quantitative method, and is responsive to changing sets of assumptions. This article focuses on the importance of separating unique and market risk in applying options theory to R&D projects, since the former impacts value negatively while the latter enhances value. It also illustrates how the hidden options in a new venture can contribute enormously to value, especially in fast-growing industries and in markets exhibiting high volatility.*

The extraordinary premiums being paid for technology stocks have caused observers to wonder whether traditional modes of valuation are obsolete. New companies which are losing money (and hence cannot be valued using price-earnings ratios or multiples of EBIT or EBITDA[1], and for which there are minimal physical assets, are being valued instead at huge multiples of revenues or projected revenues. This has led to the coining of that famous phrase "irrational exuberance" and to the declaration by some business gurus that "DCF[2] is dead." Quite coincidentally, this extraordinary phenomenon is occurring at a time when business thinkers are taking a much more serious view of what are being called "real options." [3,4]

Real options represent the application of options methodology to business situations (as contrasted to financial options, which apply to publicly traded securities, currencies, and commodities). In a typical financial option transaction, one can purchase a call option on a common stock. One makes an initial investment to purchase the call. The option may be exercised at a pre-agreed "strike price", which involves a second, but optional investment. The stock is then delivered by the seller of the call and can be liquidated for cash.

For example, one might purchase a call on a stock selling at $100 for $5. If the stock rises to $110, one next exercises the call paying $100. If the stock is liquidated the second transaction nets $10 and the entire transaction $5.

Real options are analogous. Their usefulness is gaining attention because they capture the value of managerial flexibility in ways which *a pro forma* DCF model alone cannot. Of course good managers have always understood their options under changing circumstances, and arguably a good portion of their tactical skill was to recognize and evaluate the available options. But they did this intuitively, based on experience and knowledge of markets and technology.[5] In today's world, where assets change hands rapidly and some of the decision-makers lack an intuitive knowledge of the businesses they are dealing with, financial valuation must supplement or replace intuition.

In a previous paper, the author noted that “neglecting the options approach was one of the “Traps, Pitfalls and Snares in the Valuation of Technology”[6]. Space considerations prevented going into more detail. This paper is intended not only to clarify some key points regarding the treatment of risk, but more importantly to explain why options theory can go a long way to explaining the extraordinary valuations accorded some technology investments.

An analogy

Real options today are being applied to the decision to explore for petroleum. Let us assume that corporate geologists have identified a promising geological structure. They have the expertise to estimate the probability of success (not having a dry hole), the probable size of a reservoir if one is discovered (related to the size of the reward), and the cost of building production facilities to exploit it.

Evaluating the financial opportunity involves a sequence of cash flows: 1) an investment in an exploratory well and a lease on the land, 2) an investment in production facilities, and 3) a cash flow stream from sale of petroleum until production is no longer economical. The latter will depend on the price of oil at the time it is produced. In a classic DCF analysis, the two investments and the resulting cash flow stream will be aggregated to give a net present value (NPV). Let us assume NPV is negative, and that a traditional manager would turn down the project.

However, the price of oil in the DCF model is at best an educated guess. The analyst might use the current price, or a “conservative” estimate arrived at by some internal process, or he may be slightly optimistic about price inflation. But options analysis provides a better way. For, while future oil prices are entirely unknown, there is extensive data on the volatility of petroleum prices, which allow an option value to be calculated.

A manager using real options thinking would view the first investment in exploration as the purchase of a call on an option to produce. The strike price – the price at which that option can be exercised, is the cost of the second investment, for the production facility. The value of the underlying security is the value of the oil to be produced less the cost of lifting it. A financial value can be assigned to this stream based on the ***current*** market price of petroleum, and its volatility.

The issue is no longer whether the NPV is positive! If in fact the value of this call exceeds its costs, specifically the investment in exploration and production, it is rational to make the investment. This can occur, particularly for volatile markets, even when NPV is negative.

Let us look at this situation in common sense terms. Let us assume the cost of exploration is 1 million dollars, and the cost of production facilities is $5 million. The manager may reason, "I have no idea of the future cost of oil, but if it doesn't get any better than this, I would never produce this well. But if and when it does rise, I have the option to invest the $5 million and start producing. And better yet, I am in a position to calculate whether the cost of the option ($1M) is worth the price."

Let us put some more numbers on this example: Assume that $1M is the proposed investment for a 4-year lease and an exploratory well. This is the *cost* of the option. Let us also assume the geologists estimate a one in four chance of finding oil whose present value, based on current oil prices, is $20M. Unfortunately, oil prices are at a cyclic trough and the cost of production facilities is also $20M, just equal to the present value of the revenue stream. Therefore, the investment in production is a wash and creates no value <u>even</u> if oil is found. The NPV of the entire venture is a negative $ 1M.

However, we can still make a case for the investment: First let us address the market risk in the value of the option to produce. This is a four year option with a strike price of $20M. The underlying security, the oil revenue stream is "at the money", also $20M. A look at a table of implied volatilities for commodities suggests oil prices have an annual volatility of about 30%. Using a Black-Scholes calculator we find that this option has a value of $6.35M. This is driven entirely by the possibility that oil prices will rise over the next four years.

Second, we must now factor in the unique risk. There is a 75% chance that the option to produce will be worthless because there is no oil to be found, and a 25% chance that we will exercise an option worth $6.35M. Hence the value of the option, after factoring in the unique risk, is 0.25 x $6.35M or $1.59M. The value of the option then exceeds its cost by $0.59M, and the decision to explore is eminently supportable.

Unique risk diminishes the value of this option, while market risk enhances it. Note also that we depend totally on the expertise of our geologists in estimating unique risk, whereas an estimate of market risk is basically available to all investors.

Note that there are two elements of risk here. One is the *unique risk* that the hole will be dry or that the reservoir when found will be smaller than the geologists' best estimate. In this area, the manager is on his own. But he is not without resources. He can estimate the unique risk from the corporate database, government data, technical publications, or industry benchmarking to determine the odds of a dry hole, and even the probability distribution of reservoir size. There are excellent modeling tools available[7] to help him with his calculations.

These considerations apply directly to both the exercise price and the value of the underlying security – for example, if the there is a 75% chance of a dry hole, the probability-weighted investment is 25% of $5 million, as is the probability-weighted value of the petroleum revenues. The quality of the manager's estimates will greatly affect his financial performance.

Obviously, the higher the unique risk, the lower the value of the venture.

Although he is on his own, there is a way for him, nonetheless, to reduce unique risk – diversify. The manager can invest in dozens or hundreds of exploratory wells, by increasing his bet or by joining drilling syndicates.

The second-type of risk is market risk. This is the risk that the oil price will be low or high. If you are in the oil business, there is no way to avoid this risk. But you can *value* it using options analysis. And market-based risk (volatility) always increases the value of an option, which is why calls on Amazon.com are more highly priced than calls on Exxon.

In brief, unique risk can be analyzed with the use of probabilities. Market-based risk can be analyzed by well-known tools of corporate finance: the Black-Scholes formula or the binomial approximation. They have diametrically opposed characteristics – unique risk lowers value and market-based risk increases it.

These ideas are hardly theoretical: they are reflected today in the very real way in which stock markets and option markets price securities. If the theories were significantly wrong, huge arbitrage opportunities would be created. The stock market pays no premium for unique risk, because investors have the option of diversifying unique risk away. It sees little value for a company operating natural resource and manufacturing assets, because a financial manager can buy a diversified portfolio of companies in each of these businesses. On the other hand, it exacts a penalty for market-risk: the cost of equity it demands for highly volatile securities is higher than for more stable securities.

But for the options holder, the situation is turned on its head: the more volatile the underlying security, the more valuable the option. Quoted option prices and historical volatilities are both available on the Internet, as are Black-Scholes option calculators. My experience is that calculated values and quotes track closely unless market anomalies are in play.

Relationship to R&D

In the example above, we intentionally used a physical asset such as oil rather than an intellectual asset such as technology. We did so because the example is clear, concrete, and represents practices used in the petroleum industry today. But the analogy to R&D is very strong because the sequence of investments is similar. The first investment is a search for knowledge. The second investment typically capitalizes a new business opportunity and is larger. And the reward is a sequence of cash flows until the asset is depleted or marginalized.

Let us construct the R&D analogy: Assume a drilling mud supplier engages an R&D contractor (say a specialty chemical company which produces alumina) that has patented a new concept for a superior drilling mud. The estimated cost of completing the R&D and testing in an existing well is $1M, and the probability of technical success is 25%. The R&D contractor negotiates a deal whereby the technology reverts to him after 4 years if the drilling company does not commercialize it by that time. The present value of the cost savings of the new mud (net of royalties to the R&D contractor) is $20M, but it will require an investment of $20M for manufacturing and distribution facilities. The drilling mud business is moderately volatile; the volatility of stocks of the major mud suppliers is 30%. From a financial viewpoint, the option created by this R&D scenario would have the same cost and value ($1.59M) as the commodity scenario in the box.

The element of unique risk is captured in estimated probabilities of success. Many companies have a database of project histories[8] that give guidance to such probabilities. Others use intuition. Both approaches are defensible, because each project, like each drilling site, is unique in some way. Each time new data are gathered, the element of unique risk changes in some way, but in general, successful R&D is a systematic reduction of unique risk.

Market risk is also present in nearly every project. The oil driller is ever-conscious of the situation in the Middle East. The R&D manager must equally keep an eye on his industry. In the early 90's, the political uncertainty over health care depressed pharmaceutical stocks. Obviously, the investment community felt the pain. However, the R&D community also shared it – for the reduced valuation of future rewards indirectly affected the perceived value of each project, and the willingness of shareholders to finance it. Projects where NPV's went negative were likely to be cut even if the unique risk was unchanged!

I had an illuminating professional experience with the issue of unique vs. market risk in the 1980's. There appeared then to be enormous opportunities in the development of innovative environmental technologies. My company developed and patented a small portfolio of new catalytic technologies for controlling air pollution. Unfortunately, none of them met the initial expectations of commercial success, despite largely meeting the technical and economic specifications that had been set. For years, I implicitly viewed the situation as a manifestation of unique risk: that there was a probability of technical success, a probability of commercial success, and an overall probability of success that was a product of both. It was an "easy mistake" to attribute our disappointment to unique commercial risk, for it seemed that each year the market became smaller and its inception more distant in time, prompting eventual termination of the projects.

There were indeed unique commercial risks - competitors, for example. But the competitors did not get particularly rich either.

However, it looks different in hindsight. During this time period, virtually the entire environmental technology market - air pollution, water pollution, incineration, remediation - turned sour. Very few promising new environmental technologies earned a decent return for their owners regardless of the sector of the market they were in. As a result, major environmental companies badly underperformed the stock market averages, while venture capitalists learned to reflexively refuse to finance new environmental concepts. It probably doesn't matter what caused the sector to decline, although my belief is that proposed regulations were impeded by political forces, and more potential customers created alternatives to unwanted environmental investments, than investors, technologists, and regulators anticipated.

The important conclusion is that market risk was also at play. This point is not academic, for if we attribute market risk to unique risk in calculating value, options theory tells us we will get erroneous results.

Reworking a Classic

Now let us consider how options analysis can lead to very high valuations by reworking a classic problem – the fictional Blitzen Mark I MicroComputer case from the Corporate Finance textbook of Brealey and Myers.[9] The proposition is essentially this: There is a proposal on the table to produce a new computer model, the Mark I, which will require a first year investment in capital and net startup costs of $450M. The business runs for 6 years, and is harvested in the fifth and sixth years per the attached schedule.

Schedule of Cash Flows (M$) from Mark I Case

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
After-tax Operating Cash Flow	($200)	$110	$159	$295	$185	$0
Capital Investment	$250	$0	$0	$0	$0	$0
Increase in Working Capital	$0	$50	$100	$100	($125)	($125)
Net Cash Flow	($450)	$60	$59	$195	$310	$125

The hypothetical CEO turns down the project because he has set a hurdle rate of 20%, and using that rate as a discount rate the net present value of the cash flows is negative, -$46M. (This implies that the cash flow stream in years 2-6 has a present value of $450M - 46M or $404M).

The hypothetical CFO, however, is a real options advocate. She argues that the Mark I project carries with it an *option* to build the Mark II, three years hence.

The Mark II is forecasted to be no more profitable than the Mark I, but because of the high growth rate of the industry, it will be double the scale of the Mark I, that is it will require a $900M investment in year 4, but throw off double the cash flows in years 5 through 9. Therefore, its cash flow stream is worth $808M in Year 4 or $462M when discounted back to Year 1.

The CFO characterizes the Mark II as a three-year call option on an asset valued at $462M with a strike price of $900M. Using the Black-Scholes formula she finds that this is worth $55M, assuming a volatility of 0.35, which is reasonable for a computer stock.[10] This volatility is a proxy for the fact that it will be difficult to forecast Mark II revenues and margins in years 5 through 9, but they might be either better or worse than forecasts the Mark I. If they look better, the decision can be made to build the Mark II.

Her argument is that, with the embedded option to build the Mark II, the real value of the Mark I is the sum of the proforma enterprise value $-46M and the $55M option value, or a positive $9M. Hence, the decision should be to move ahead.

Leaving aside the question of whether a $450M investment decision should hinge on a difference as razor thin as $9M, it is worth reflecting that this analysis depends critically on both the growth rate of the computer industry and the volatility.

Consider the growth rate first. If the growth rate were zero, then the Mark II would be the same size as the Mark I, and the option value would be halved: $55M ÷ 2 = $27.5M. This would not be enough to offset the -$46M enterprise value, so the decision would be negative.

Let us now think of what this decision would look like if the growth rate were at “Internet speed”, say 10X in three years instead of 2X. Then the option value would have a value 5X as large as the 2X case, or 5 x $55M = $275M. This swamps the -$46M, and gives a total value of $229M. This now looks like a great project based on options thinking.

But there is more – we haven’t considered volatility. The value of an option is directly proportional to the volatility parameter σ of the stock (σ is the percent standard deviation of the stock price on an annual basis), and it is not unusual for Internet companies to exhibit volatilities of 1 or higher.

Let us consider the implications of a volatility of 1.0. Then the value of this option is $275M x (1.0/0.35) = $786M, and the value of the deal is $786-$46M = $740M. In this scenario, the enterprise value is completely swamped by the option value.

All of this is of course entirely rational, as long as the growth is maintained, and the volatility remains high. Indeed, in the textbook case, there is a rather coy (but correct) remark by the CFO, that the Mark II carries with it a call, which she ignores, to build a Mark III, etc., so the real value should in effect consider a cascade of compound options, that could justify even higher valuations!

This is no small point, because we may consider that the Mark I may have had embedded in it many other options we now associate with small computers: the potential to chat or shop on-line, to be a home entertainment center, and to manage a sophisticated suite of office software. Whether those options were implicitly recognized or effectively exercised is another matter: neither IBM nor Apple became Microsoft, AOL or Yahoo! However, the options of coupling PC's and their operating systems with unknown emerging technologies and markets were hidden but in hindsight indisputably there. So the lesson of the Mark I case is not just the option to build the Mark II, or the even more valuable option to build Mark II, III, IV, etc., - the most important option is to exploit the platform to couple the technology with emerging technologies and markets.

The purpose of this section is of course not to argue that sky-high valuations are justified for microcomputer, operating system, or Internet companies – only to argue that they may be financially rational based on certain sets of assumptions. There are also well-defined limits even to the value of options, and my own calculations often indicate that "momentum investors" may bid a stock up to the point where it is overvalued, even on an options valuation basis. Or maybe they are thinking about options I can't identify. But options thinking goes a long way to explaining why the conventional valuation ratios just aren't enough.

January 17, 2000

Dr. F. Peter Boer is the CEO of Tiger Scientific Inc. and the John J. Lee Adjunct Professor of Chemical Engineering at Yale University. He teaches "Valuation of Technology" at the Yale School of Management and is the author of a book by that title (John Wiley & Sons, NY, 1999). He is a former Executive Vice-president of W.R. Grace & Co. and a Past-president of the Industrial Research Institute. Contact fpboer@alumni.princeton.edu or browse to www.boer.org.

[1] Earnings before interest and tax (pretax operating earnings) or Earnings before interest, tax, depreciation and amortization (pretax operating cash flow).
[2] Discounted cash flow valuation.
[3] M. Amram and N. Kulatilaka, "Real Options; Managing Strategic Investment in an Uncertain World", Harvard Business School Press, Boston, MA, 1999.
[4] L. Trigeorgis, "Real Options; Managerial Flexibility and Strategy in Resource Allocation", The MIT Press, Cambridge MA, 1998.
[5] Trigeorgis (op.cit.) makes a very powerful point. He analyzes a business scenario in which the investor has five different real options (p. 227ff) - this is not a large number compared to real world managing. He demonstrates that each additional option adds more value to the base case (some options are much more valuable than others). However, the complexity of the calculations also increases dramatically as multiple interacting compound options are included, and to my mind so does its distance from business reality. Hence, it would be illusional to conclude that rigorous options analysis is a substitute for managerial skill. The real conclusion is that with options included many projects are demonstrably better than NPV alone tells us.
[6] F. Peter Boer, *Research•Technology Management*, Sept-Oct. 1998, 45-54; *Chemtech*, 29, Number 1, 14-211999. The RTM article contains an erratum: β should be replaced by σ in the formulae.
[7] Crystal Ball ™ , Decisioneering, Inc., Denver, CO.
[8] F. Peter Boer, *The Valuation of Technology*, New York: John Wiley & Sons, 1999, pp. 281-4.
[9] R.A.Brealey and S.C. Myers, "Principles of Corporate Finance", McGraw-Hill, NY, 1996, pp 590-591.
[10] A reviewer has communicated his concern about the use of stock volatilities as a proxy for market risk. The author shares this concern to the extent stocks and technologies have unique characteristics. Nonetheless, the practice has been adopted in the literature of real options per the Brealey and Myers example above, and is discussed in some detail in Amram and Kulatilaka (op. cit., pp. 100, 212-4.) Merck uses a range of volatilities characteristic of the biotech industry for valuing pharmaceutical projects, in essence performing a sensitivity analysis (Nancy A. Nichols, "Scientific Management at Merck: An Interview with CFO Judy Lewent*", Harvard Business Review*, January-February 1994, 91.