Evaluating the Results of the UK 3G Spectrum License Auction- Does a Real Options Approach Make Sense?

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Abstract

A number of different methods, including discounted cash flow analysis, Monte Carlo simulation, and real options analysis (ROA) were used to assess the value of third generation (3G) UK wireless spectrum licenses to a new entrant company. The value of managerial flexibility to expand or abandon the project in the future was estimated in an effort to help explain the high prices paid in the 2000 3G UK spectrum license auction.

We estimated that the value of the spectrum license to a new entrant was £2.6B, with the value of the flexibility to expand or abandon the project making up approximately £100M of that value. The £2.6B valuation with flexibility is far below the £4.39B actually paid by the new entrant bidder in the 2000 auction. The paper briefly examines some specific reasons for the overpayment, including the presence of investor irrationality (e.g. a speculative "bubble") and the "strategic value" of the license not taken into account in the analysis.

The analysis concludes with an examination of optimal management behaviors with respect to the options available and relative to changing levels of uncertainty.

Introduction

Overview

The 2000 auction for United Kingdom spectrum licenses for so-called Third Generation, or 3G, wireless services was notable in the high prices it commanded for the five available licenses. Winning bids for the licenses totaled £22.5B, more than four times what analysts and industry experts had originally predicted.[1]

Valuation using the traditional methodology of Discounted Cash Flow (DCF) analysis does not appear to justify the high prices paid for the spectrum licenses. However, DCF may not accurately reflect the full value of the licenses. In particular, DCF does not capture the value of managerial flexibility, or "real options", available to the winning companies. Using Real Options Analysis (ROA), our team's goals were to:

1. Determine the value of managerial flexibility to a "new entrant" 3G license winner and determine whether or not that value helps to explain the high prices paid in the auction
2. Determine the key decision making principles around which the management team of a license holder should exercise or not exercise their managerial options in the future.

Background

Third generation wireless (3G), also known as Universal Mobile Telephony System (UMTS), is the name given to the "next-generation" of wireless technologies and standards. (1G was the term given to the earliest analog networks, 2G the name given to more advanced digital networks, and 2.5G the name given to upgraded 2G networks that supported higher data speeds.) The most important characteristics of these new networks are the high data speeds and increased capacity for service that they offer. 3G networks will enable data speeds of up to five times greater than the most advanced 2.5G networks available today. These high data speeds could enable applications such as speedy access to corporate networks and the Internet, video-on-

[1] Dresdner Bank

demand, online shopping, and video conferencing, all via a mobile device.[2] More importantly, however, the additional 3G spectrum enables incumbent wireless companies to build out their capacity in order to support more customers and to enable high-bandwidth services in an environment that is increasingly becoming capacity-constrained.[3]

The UK government decided to auction off licenses for five pieces of spectrum (A, B, C, D, and E) in an auction beginning in March of 2000. According to the British government, " a five license auction is intended to deliver the Government's objective for the efficient use of the spectrum, and, in particular, will encourage market entry and sustainable competition by ensuring that at least one New Entrant can enter the UK market."[4] To fulfill this requirement that a new entrant be involved in the 3G market, bidding on License A was restricted to new entrants. Any firm, new or incumbent, could bid on the other four licenses. The licenses had a length of 20 years.

The results of the auction were shocking. On March 30th, 2000, the total value of the leading bids reached £7.2B, an amount that industry experts noted was "more than 3 times the original estimates."[5] By the time the auction ended the total value of the bids was £22.5B, an amount that was dramatically higher than expected and that left analysts scrambling to adjust their market projections. The complete results of the auction are shown in Table 1.

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[2] United Kingdom Spectrum Auction Information Memorandum, NM Rothschild & Sons, Radiocommunications Agency, 1 November 1999
[3] Lehman Brothers, March 23, 2000
[4] United Kingdom Spectrum Auction Information Memorandum, NM Rothschild & Sons, Radiocommunications Agency, 1 November 1999
[5] Merrill Lynch, "UK 3G Auction: Onwards and Upwards", March 30, 2000

License	Winner	Spectrum	Price (£ Billions)	Price/Mhz (£ million)	Price/pop (£)
A	TIW Mobile	15 paired, 5 unpaired	4.39	125	73
B	Vodaphone	15 paired	5.96	199	99
C	British Telecomm	10 paired, 5 unpaired	4.03	161	67
D	One2One	10 paired, 5 unpaired	4.00	160	67
E	Orange	10 paired, 5 unpaired	4.10	164	68
Total/Average			22.48	161	375

Figure 1 - British UMTS Auction Results

Methodology and Valuation

Our analysis examines three separate tools that decision makers could have used to analyze the 3G opportunity, as well as the valuation insights that these tools contain:

1. Discounted Cash Flow (DCF) analysis
2. DCF analysis incorporating uncertainty
3. Real Options Analysis (ROA)

Each of these methods builds on the preceding method. In other words, DCF incorporating uncertainty (Method 2) is simply the DCF model of Method 1 with additional uncertainty modeling characteristics "layered" on top of it. Similarly, methods 1 and 2 are integral parts of the methodology used for Method 3, Real Options Analysis, as laid out by Copeland and Antikarov [CA] in their book, "Real Options: A Practitioner's Guide."

Intuitively, what is a real option? A real option is the right, but not the obligation, to take an action (e.g., to defer, expand, contract, or abandon a project in the future) at a predetermined cost, called the exercise price, for a predetermined period of time – the life of the option.[6] The flexibility inherent in these decisions is not captured in traditional DCF analysis in which a project is distilled down into a single Net Present Value on which a discrete go/no-go decision is based. Take the example of purchasing an oil well. Based on initial surveying results, the owner could estimate the amount of oil in the well, and based on forecasts of oil prices, could estimate the NPV of the project, without incorporating the value of flexibility. What this value does not incorporate, however, is the flexibility, the "real options" available to the well owner. These options- the ability to expand, contract, or even delay oil extraction depending on actual prices and more accurate information of the well's actual oil reserves - have the potential to dramatically increase or decrease the value of the well. The flexibility inherent in real options adds value, value that is not captured by traditional NPV analysis.[7] CA goes as far as saying that "NPV systematically undervalues business opportunities."[8]

CA's methodology for Real Options Analysis (ROA) is made up of four steps, outlined in Figure 1 below. As noted above, Step 1 of the framework, the creation of a "base case" DCF analysis for the project in question, corresponds to our examination of DCF as a stand-alone valuation technique. Similarly, Step 2, identification of uncertainty, corresponds to our incorporation of modeled uncertainty into the DCF analysis. As a final step, we will combine these two stand-alone analyses with the modeling of managerial flexibility and the calculation of the real options in question in order to complete our analysis.

[6] Copeland and Antikarov
[7] Ibid
[8] Ibid

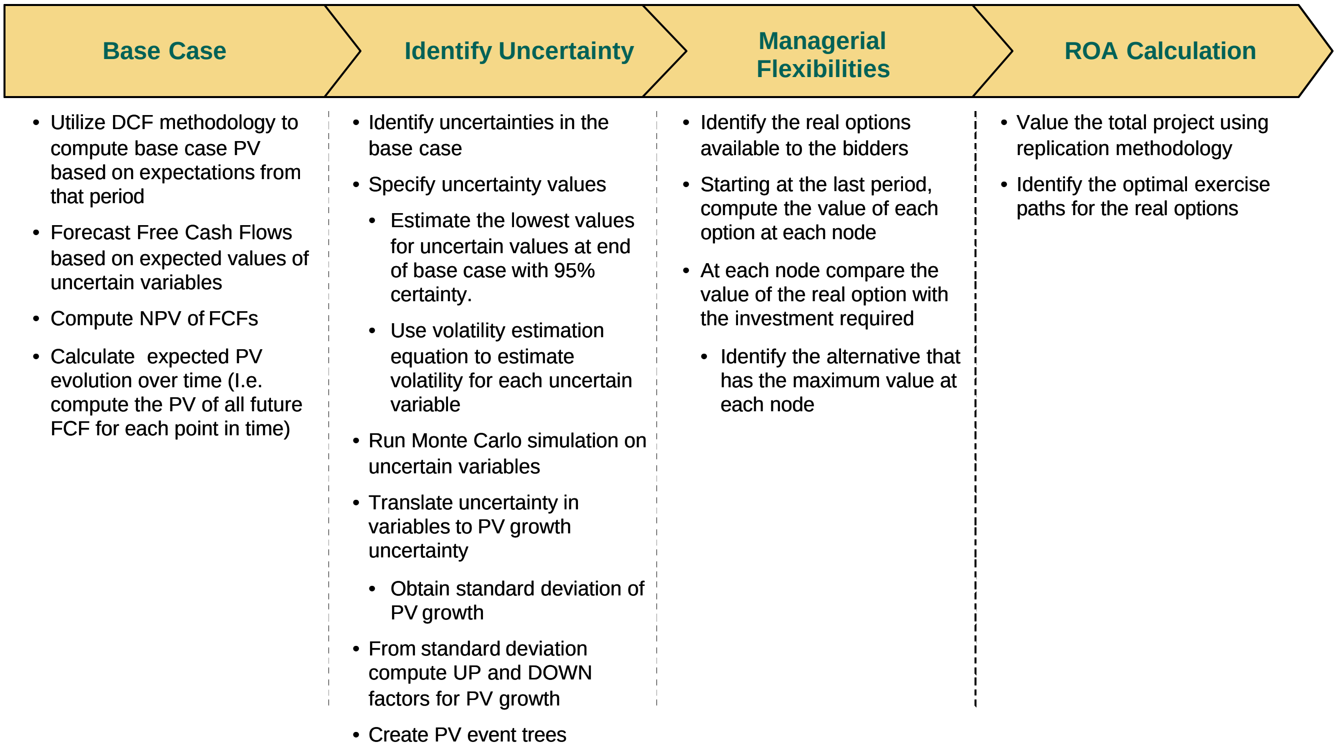

Figure 2 - Four Step Real Option Methodology

We chose to use these methods to value License A, the 3G spectrum license reserved for a new entrant bidder. Incumbent wireless carriers such as Vodaphone or BT Wireless most likely perceived significantly more strategic value in the licenses than a new entrant would have. More specifically, an incumbent's failure to win a bid for a 3G license would likely been seen by customers and shareholders as a failure to commit to a vital future technology and negatively impact the value of their current business. This could have been devastating from a marketing standpoint, particularly for the most demanding, high value corporate customers. Accordingly, a part of the 3G license's value for an incumbent in that it was strategically necessary for the carrier to retain its most profitable customers.[9] This strategic value, however, is extremely difficult to quantify. Strategic value, while not insignificant for a new entrant bidder, certainly

[9] Interview with Steve Jordan, BT Wireless, 8/2001

would have been less of a factor than for an incumbent. Therefore, by focusing on new entrant bidders, we can restrict ourselves to valuation based on the future cash flows from operating the business in the future.

Prior to detailing our findings, it will be useful to describe the sources of managerial flexibility available to the holders of UK 3G spectrum licenses. Our team traveled to the UK in August of 2000 and engaged in a series of meetings with UK wireless industry participants and analysts that illuminated, at a high level, some of these sources of flexibility. The first source of flexibility that incorporated in the model was the speed at which a company builds out its network coverage. Under the terms of the 3G license agreement, a winning company is required to achieve 80% population coverage by the year 2007. The company has an option, however, regarding if and when it builds out the final 20% of its coverage. This is the first real option available to 3G managers. The second option is the decision of whether to expend additional capital to increase the capacity, or bandwidth, of the 3G network. A company's initial 3G network will most likely have the bandwidth to support a sub-set, but not the entirety, of 3G applications. In other words, it might support the downloading of music, but might not support fully mobile video teleconferencing. Conceivably, these higher bandwidth applications might represent incremental revenue to the wireless company. The second option that we examined, therefore, is the ability of the manager to double the capacity of the network at any point during the life of the license. As a third and final option, we assume that the wireless company can abandon its 3G license at any point in time by selling it to another company for a fixed price of £1B.[10]

[10] Interview with Steve Jordan, BT Wireless, 8/2001

Note finally that as a simplifying measure we treated the options in tandem. In other words, the coverage expansion and capacity expansion options are always exercised, or not exercised concurrently. Thus, the final set of real options that we examined were as follows:

- Real Option 1- Expand population coverage from 80% to 100% and double capacity of the network
- Real Option 2- Abandon the project for a fixed price of £1B.

In the remainder of the paper, we show the details of our DCF analysis, our incorporation of uncertainty, and our Real Options Analysis. We then discuss our findings, assessing the rationality of the auction bid price, with flexibility value taken into account, and providing an overview of optimal decision paths for management given varying states of uncertainty.

Discounted Cash Flow (DCF) Model

The DCF method is the most frequently used valuation method today and captures the expected profitability of discrete scenarios. As a first step in our analysis, our team constructed a DCF model to derive an estimate of the value of a 3G license to a new entrant bidder. The assumptions used in the model reflect expectations at the time of the auction. Most of these assumptions are taken from investment banking research reports.

The model is comprised of the following sections: subscribers and average revenue per user (ARPU), operating expenses, capital expenses, and taxes. The first step is the calculation of revenues, which are the product of the number of subscribers and of the average revenue per user (ARPU) for those subscribers. The number of subscribers is driven by the market penetration at any given point in time multiplied by the potential market of 48M people, or the 80% of the population initially covered by 3G service. If the option to expand coverage to 100% of the population, Real Option 1, is exercised, the appropriate portion of the incremental 12M potential subscribers is added. Note that we have made the simplifying assumption that all members of a population would be potential subscribers. In reality, some will be too old or too young, or otherwise ineligible.

3G market penetration was estimated using the Bass Model, a formula that is often used to forecast adoption and diffusion rates for new technologies and innovations. The Bass Model Equation is given by:

$$N_t = pm + (q-p)\,Y_t - (q/m)Y_t^2$$

Where N_t is the number of subscribers at a point in time t, Y_t is the cumulative number of subscribers at a point in time, and m is the potential size of the market. The key parameters for the model are the initial trial probability p (parameter of innovation) and the diffusion rate parameter q (parameter of imitation). The innovator and imitator inputs used in the base case DCF model (.031 and .562, respectively) were based partially on the historical parameters of cellular phone adoption and partially based on the parameters implied by the analyst reports of the UK 3G market from the time of the auction.[11] For the initial trial probability, a value higher than the historical value was chosen to reflect that initial adoption will most likely happen more quickly with 3G than with the initial adoption of cellular technology, given that cellular phone usage habits are well established and that there is already a large customer base of previous generation cell phone users that can upgrade to 3G. Note that the same Bass model curve parameters were applied to subscriber growth in the initial 80% of the population covered, as well as the incremental 20% covered after the exercise of Real Option 1. The start date for the second Bass model curve, of course, shifts according to the exercise date.

[11] Dresdner Bank

The model then applies a net subscriber addition market share factor to the new subscribers for the industry in a given year. Based on an analyst report from Lehman Brothers, this assumes that, due to a lack of brand name or current customers that can be converted to 3G, the new entrant will initially be less effective than entrenched competitors at capturing new customers. Over four years, as the new entrant becomes established and develops brand recognition, this disadvantage phases out until it captures the same "fair share" percentage of new customers (20%) as each of the other four license holders in the industry. Multiplying this net subscriber addition market share factor by the number of new subscribers that are being added to the industry provides the total customers for each year for the new entrant.

The next step in constructing the model was to determine the ARPU throughout the life of the 3G license. ARPU was divided into traditional Voice Revenues and an additional, all encompassing revenue source labeled Non-voice Revenues. Non-voice revenues might include any one of the number of technologies to which 3G promises mobile access, such as Internet access, stock quotes, weather updates, data transmission, shopping, advertising, and all other revenues not directly captured in voice services. This non-voice category is then divided into "Base" non-voice revenues, revenues that a wireless company can capture with an initial investment in bandwidth capacity, and "incremental" non-voice revenues, those revenues a carrier can capture with an increase in its bandwidth, or by exercising "Real Option 1", as outlined above. The resulting voice ARPUs extend the historical trend of significant annual price declines, estimated to be 10%. As described previously, incremental non-voice revenues are assumed to be equal to Base non-voice revenues. Exercising the option to expand capacity, therefore, serves to double the total non-voice ARPU.

The product of the new entrant customer base times the revenues from voice and non-voice ARPU yields total revenues. Operating expenses, however, need to be subtracted in order to estimate the EBITDA value. In its business case analysis, Lehman Brothers has greatly simplified the way in which OPEX is handled by simply assuming a long-term EBITDA margin for each of type of operator (e.g. first-tier incumbent, second-tier incumbent, and new entrant.) Incumbent operators were expected to be able to generate high margins immediately after launch due to their access to existing organizational capabilities and resources. The new entrant, on the other hand, needs to spend much more on advertising and setting up customer service, distribution, and other expensive services. Therefore, its EBITDA margin will only be 10% of revenues for the first four years, before steadily climbing to 37% by year eight, and remains at that level thereafter.[12]

The next step in the DCF valuation was the calculation of the capital expenditures. The Dresdner analyst report of 5 May 2000 divides projected CAPEX expenditure into expenditures devoted to coverage (e.g. the initial network build-out) and expenditures devoted to capacity (e.g. subsequent CAPEX to increase the capacity of the original network infrastructure.) Since Dresdner's forecasts are for the UK 3G market as a whole, we can only infer the forecasted costs for a single new entrant. Dresdner additionally states that it expects a new entrant's CAPEX to be about 25% higher than that of an incumbent, as incumbents can leverage their existing infrastructure. If we assume that the four non-new entrants spend an equal amount, and that the new entrant's CAPEX costs 25% higher than the incumbents, we can easily determine that the

[12] Note that in reality, a new entrant would have at least 2-3 years in which it's EBITDA margin is negative. We have chosen an approach using only positive EBITDA margins in order to avoid the difficulties of a real options approach in dealing with large negative "dividends" early in the project life.

new entrant is responsible for approximately 24% of total market CAPEX. Based on Dresdner's apparently more accurate treatment of cash flows in the short and long term, we will use these numbers as our base case for new entrant CAPEX.

The final step in the DCF analysis is the calculation of taxes. We assumed that the tax rate for the new entrant will be 30%. For the first several years, depreciation expenses exceed net income and result in a net loss for the company. We conservatively assume that this new entrant is not part of a broader conglomerate and cannot use this tax shield until it reaches profitability.

We can complete our valuation of the base case opportunity by identifying the optimal year in which the wireless company can exercise its coverage and capacity expansion options. The following graph displays the expected after-tax NPV for the 3G license depending on the year in which the company exercises the option.

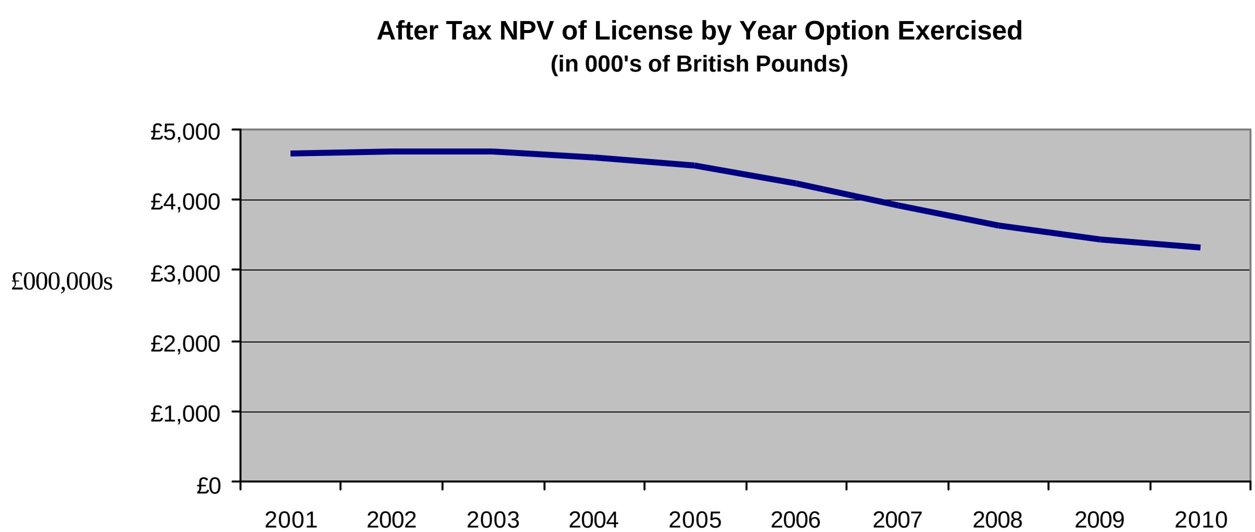

Figure 3 - After Tax NPV of License by Year Option Exercised

This shows that the optimal point to exercise the option is year 2003, providing a project NPV of £2,570. However, the less than 2.5% difference in the value of the option over the first three years is sufficiently small that other strategic factors such as first mover advantage should determine which of these first few years the option should be exercised. It is important to note that the value of the project decreases as the option exercise is delayed since the discounted cash flow method does not capture the value of the increased information about the market gained over time.

Uncertainty and Managerial Flexibility

DCF analysis provides a useful first step in any valuation project. However, not all net present values are created equal. That is, two projects, both showing the same NPV, might have substantially different risk profiles due to differing levels of uncertainty in the values of their underlying inputs or parameters.

For example, the base case valuation above is sensitive to a range of key drivers, including uncertainty about the average revenue per user (ARPU), 3G market penetration, subscriber growth, margins resulting from levels of competition, market share, etc. While many additional factors such as marketing expenses, margins, and capital requirements, will determine the profitability and free cash flows generated by these opportunities, the revenue level determines the upper limit of 3G profitability. Three drivers- 3G market penetration, incremental non-voice revenue levels, and the new entrant's market share- are particularly uncertain and important because they determine the number of customers and revenues for the new entrant. It is on these three sources of uncertainty that we will focus.

As previously described, the Bass Model inputs are based partially on the historical adoption and diffusion rates for the initial cellular phone introduction and partially on Dresdner

Bank's analysis. Applying uncertainty[13] to these factors reveals a 90% confidence interval for the NPV of the license given that the option is exercised in 2001 from £2,410 to £2,706, with a range of £296M, or approximately 10% of the value of the license.[14]

Percentile	2.5%	5.0%	50.0%	95.0%	97.5%
NPV	£2,382	£2,410	£2,563	£2,706	£2,728

Figure 4 - Impact of Varying Adoption and Diffusion Rates on NPV of License

This reveals that while adoption rates represent a significant driver, the 20 year length of the license allows enough time that, in all cases, 3G will be established before the half way point of the license life. Consequently, there will be ample time to earn revenues from the full market in these scenarios.

While the uncertainty in the rate of market penetration was not a major driver in the value of the license, the ARPU levels are likely to be more significant drivers of license value because they determine the level of future cash flows inflows and are major drivers for the free cash flows that can be generated. Of the different types of ARPU, voice ARPU levels are relatively well known and based on current data. Non-voice ARPU levels, however, involve new applications and services plus changes in consumer behavior. Accordingly, this component of ARPU is highly uncertain and assumption based.

ARPU growth rate from time period to time period was modeled using geometric Brownian motion, represented by:

$$A_t = A_{t-1}\, e^{(?????\text{^}??????\ t?????sqrt(?\ t??Z\}}$$

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[13] A triangular distribution was used to model uncertainty for p and q.

[14] Full details of the thought process that went into the selection of the Bass model uncertainty parameters are given in Appendix A

where A_t and A_{t-1} the ARPUs at times t and t-1, respectively, ? is the growth rate, ? is the baseline variability, or sigma, in the growth rate, and Z is a normally distributed random variable with mean=0 and standard deviation =1. For a baseline sigma, we chose a value of 20%.

Even with a fixed initial non-voice ARPU level with variable growth patterns, the project dependence of the project NPV on this source of revenues is demonstrated by the sensitivity of its variability to changes in the non-voice ARPU growth rate (defined as sigma). An increase in the sigma of the non-voice ARPU from 10% to 30% quadruples the standard deviation of the net present value of the project and an increase to 50% from 10% increases the standard deviation of the NPV by a factor of 10.

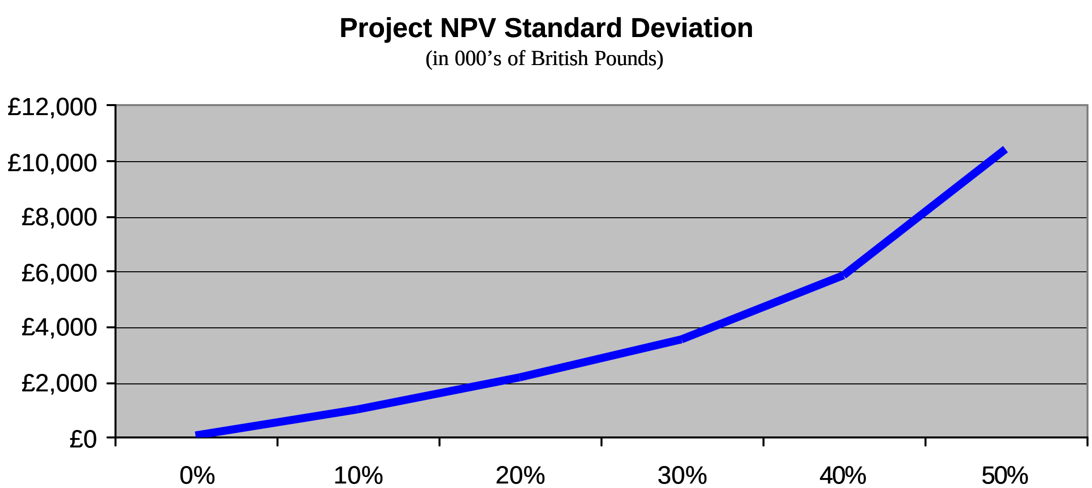

Figure 5 - Project NPV Standard Deviation

Therefore, as the uncertainty about the non-voice ARPU growth rate increases, the standard deviation of the value of the project grows dramatically. The increased variability increases the risk in the project, including the possibility that it can lose money. The increased risk reduces the value of the project since the investors, in this case the license holders, need to be compensated for higher levels of risk in the form of a lower price. The third factor of uncertainty that we modeled was the market share that the new entrant would be able to capture.

As Figure 6 illustrates, the value of the license is disproportionately sensitive to the maximum market penetration that the new entrant can achieve. The graph compares the base case of the new entrant capturing a maximum of 20% of the new entrants after several years to capturing 10% or 30% of new entrants. If the new entrant can only capture 10% of new customers, it should wait until 2004 to exercise the option and the resulting project value will be only £457. For both the base case and the case where the new entrant can capture 30%, the company should exercise the option in 2003 and the license will be worth £2,570 and £4,684 respectively. The value of the licenses increases at a greater rate than the market share because of the economies of scale, particularly for capital. The number of base stations and amount of equipment is based on a combination of geographic and capacity constraints. As the density of the customers increase through a higher market share penetration, their per person capital costs fall, improving the economics of the license.

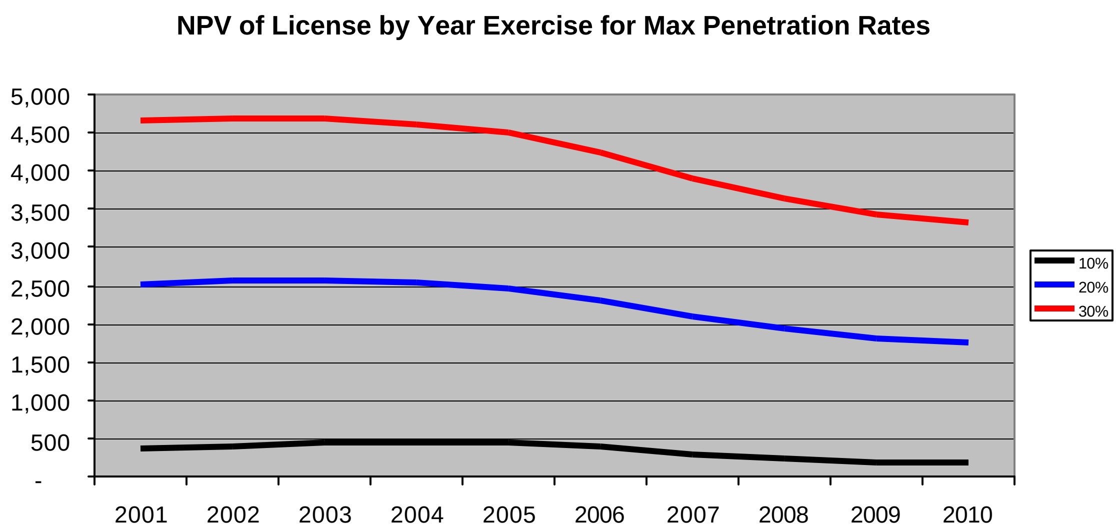

Figure 6 - NPV of License by Year Option Exercised for Max Penetration Rates

In summary, focusing on these three drivers of the value of the license showed that they impacted the project quite differently. Applying variability to the 3G penetration rate by varying the Bass Model factors did not greatly affect the value of the license and is unlikely to be a decision making driver for the license. This is due to the fact that, barring a fundamental technical problem, 3G is a replacement technology for 2G to which the big wireless telecommunication providers will need to migrate their customers for capacity reasons. While the rate of the migration to 3G may vary, it is unlikely to take more than ten years. The uncertainty in the growth rate of non-voice incremental ARPU levels proved to be an important driver in the variability of the NPV of the license. Finally, the new entrant's maximum market share had a disproportionate impact on the value of the license due to fixed costs and economies of scale.

The Copeland and Antikarov ROA framework mandates that uncertainty be explicitly modeled and, using Monte Carlo analysis, distilled into a single measure of uncertainty, that of the standard deviation of the rate of return for the project. In preparation for the complete real options analysis, this was done using the above three drivers of uncertainty. A value of 12% was found for the standard deviation of the rate of return, and this was used as the volatility of the underlying asset. This value was used to create a binomial event tree that would provide the foundation for the option valuation.

Real Options Analysis

We have seen that Discounted Cash Flow analysis yields a Net Present Value for the 3G opportunity that takes into account a single state of nature. We then identified a subset of the managerial options available and used a modification of our DCF model to identify the optimal year in which those options should be exercised. Again, this assumed a single state of nature.

Next, we considered multiple states of nature by choosing three underlying sources of uncertainty with regards to the value of the 3G market. We used Monte Carlo analysis to examine the impact that these sources of uncertainty had on the volatility of the value of the project. This allowed us to better understand the relationship between uncertainty and project value.

What we haven't examined yet, however, is the actual value of the flexibility available to managers in the case of the build-out of a 3G wireless business. More specifically, what is the value of the 1) the right, but not the obligation, to expand coverage and capacity at a given future point in time, 2) the right, but not the obligation to abandon or sell the business for fixed price at a future point in time.

To determine this, we used the four-step Real Options Analysis (ROA) methodology proposed by Copeland and Antikarov [CA] and described previously. We have already discussed Step 1 of the process, computation of the base case present value of the project without flexibility, and Step 2, modeling of the uncertainty using an event tree. Step 3 involves the identification of managerial flexibility, real options, and the incorporation of these flexibilities into a decision tree. As discussed previously, the two options that we chose to model are 1) the option to expand capacity and coverage at a future point in time for a designated strike price, 2) the option to abandon the 3G market at any time for a fixed price of £1B.

Our analysis showed that the value of the project with flexibility was approximately £2.6B, and that the value of the flexibility (defined as the value of the project with flexibility minus the value of the project without flexibility and assuming the expected value of £2.5B in the optimal exercise year) was approximately £100M.[15]

In order to fully understand this number, it is necessary to examine the factors that drive option value and the sensitivity of option value to each of these items. CA identifies five items that affect the value of an option. They are:

[15] Expanded technical details of the Real Options Analysis are shown in Appendix A

?? The value of the underlying risky asset

?? The exercise price

?? The time to expiration of the option

?? The standard deviation of the value of the underlying risky asset

?? The risk-free rate of interest over the life of the option

?? The dividends that may be paid out by the underlying asset

We will briefly discuss the impact of each of these on our analysis in turn.

First, the value of our option is sensitive to the expected, or base case, net present value that forms the foundation of our event tree, and therefore our real options analysis. As the value of the underlying asset increases, the value of the option increases as well.

Option value is also sensitive to the exercise price of the option. The exercise price for the expansion option in our case is made up of both the cost to expand coverage nationwide at a fixed point in time, as well as the cost to expand capacity. The cost of the coverage expansion we hold as a fixed £461M, the present value of the cost of a six-year build-out that can be initiated at any point in time. The cost of capacity expansion, however, is slightly more complex, consisting of both the present value of the additional per-subscriber capital expenditure at each future point in time, as well as the up-front cost of upgrading all existing customers to the higher capacity service. Thrown on top of this is the fact that the per-subscriber capacity expenditure decreases over time as the cost of new technology decreases and as scale economies kick in.

The third driver of option value is the time until expiration of the option. An increase in the time to expiration increases the value of the option. As we are dealing with a pre-defined twenty year life for our option, we will not examine the effects of changes in this number on option value.

Perhaps one of the biggest drivers of option value is the fourth driver, the volatility of the underlying asset, expressed as the standard deviation. In our case, we used Monte Carlo simulation to combine our estimates of uncertainty surrounding two market parameters, non-voice ARPU and subscriber growth, into a single measure of volatility, that of the rate of return of the 3G market opportunity. This rate of return defined the "up" and "down" states of our event tree. How do changes in this volatility drive changes in the rate of return?

As Figure 7 shows, the value of the option increases as the volatility of the underlying

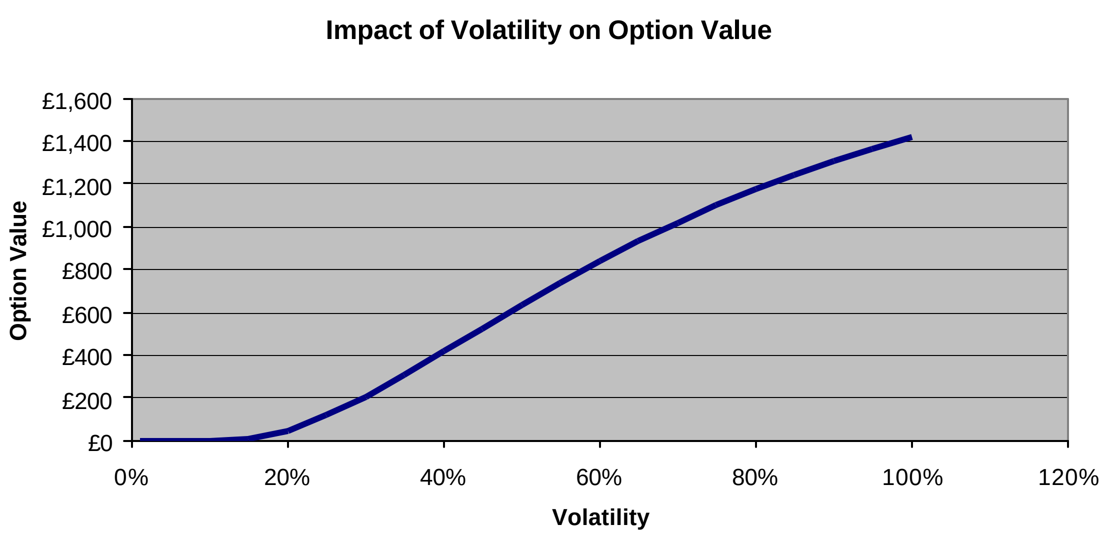

Figure 7 - Impact of Underlying Variability on Option Value

asset increases. Intuitively, this makes sense; in the face of a greater range of future outcomes (increased volatility), the flexibility for managers to react in response to these outcomes is worth more. Interestingly, we see little effect option value at lower ranges of volatility. Option value remains relatively constant in response to volatility until volatility reaches approximately 20%, at which point the option value starts to rise. It is significant to note that in choosing to model only two of what is a large number of potential market value uncertainties, we have almost certainly underestimated the volatility of the market returns, and thus underestimated the value of the option.

The risk free rate can also serve as a driver of option value. According to Copeland and Antikarov, any increase in the risk free rate "will increase [option value] since it will increase the time value of money advantage in deferring the investment cost."[16] This point can be illustrated through a financial option on a security. One can achieve possession of a security at a specified future date through either of two equivalent methods. The first is to simply purchase the security now and hold it until that date. The second is to purchase a call option to purchase the security at that date and invest the discounted value of the strike price in risk free bonds. The higher the risk free interest rate, the less that one needs to invest, increasing the value of the option. As shown in Figure 4, changes in the risk free rate of return can have a significant impact on option value. Doubling the risk free rate from 5% to 10%, for example, changes the option value by 216%.

[16] Copeland and Antikarov

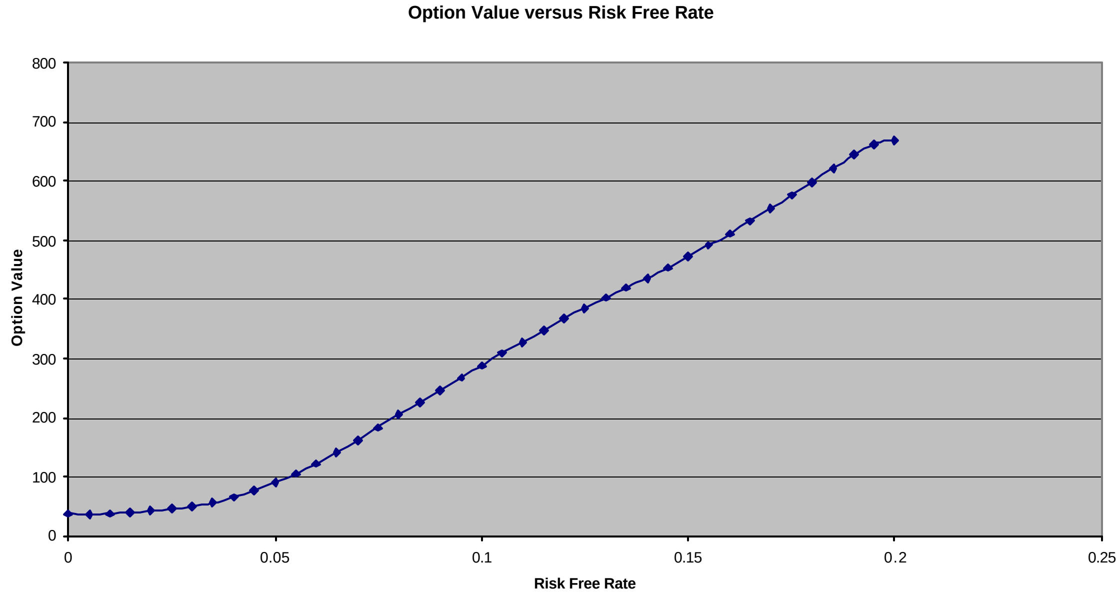

Figure 8 - Option Value versus Risk Free Rate of Return

The final driver of option value is the amount of dividends lost to competitors who have out-performed us. A competitor who exercises the option earlier may gain a first mover competitive advantage that reduces the likely market share and future cash flows gained by exercising the option. We assumed a fixed share of net additions for our business case, and thus did not model this.

Findings

Rationality of Auction Results

During the UK 3G spectrum license auction in April, 2000, TIW, backed by Hong Kong conglomerate Hutchison Whampoa, won License A with a bid of £4.39B.[17] The winning bid for license A, as well as for the other four licenses, greatly exceeded original expectations for bid prices. In late March, 2000, for example, shortly before the end of the auction process, Lehman

[17] Dresdner Kleinwort Benson Research, May 2000

Brothers estimated that a license was worth £2B to a new entrant, and that the new entrant could therefore justify paying £700M to £1.2B for the license (assuming a requirement for a 15-25% return on capital employed.)

The great disparity between estimates of what the 3G opportunity is worth to a new entrant, and what was paid for the right to participate in that opportunity, is one of the main issues that prompted our research. What is our estimate of the value of the 3G opportunity? More importantly, what is our estimate of the value of flexibility available to the manager of a 3G new entrant. Does taking this value of flexibility into account help explain the high license prices?

As a note, we decided to use a straightforward criteria to assess the attractiveness of the 3G opportunity for a new entrant, in which the present value of the 3G opportunity plus the value of flexibility has to equal or exceed the cost of the license. This method, chosen because of its simplicity, is equivalent to calculating the return on the project and testing whether the IRR exceeds the firm's Weighted Average Cost of Capital (WACC) of 8.5%.

Our analysis showed that the expected value of the license, not taking into account flexibility and uncertainty, was £2.5B. This assumed that the coverage and capacity expansion options were exercised in the optimal year of 2003. Additionally, our analysis showed that the value of flexibility was approximately £100M, for a value of the project with flexibility of £2.6B. At first glance, this indicates a negative NPV of the project of £-1.8B, arrived at by subtracting the £4.39B cost of the license from the value of the project with flexibility. Before finalizing our conclusion, however, and examining some reasons for this irrationality, let's examine these numbers in slightly more detail.

First, recall that the value of the project without flexibility of £2.5B is only an expected value based on a specific scenario. It does not reflect the large amounts of uncertainty in many of the underlying variables. The effects of only two possible sources of uncertainty, subscriber growth and non-voice ARPU levels, can be shown via Monte Carlo analysis.

Managers might use Monte Carlo analysis to determine whether or not there is a reasonable probability of achieving positive NPV, even if the expected value results in negative NPV. As the results below show, management can be 95% confident only that the value of the project will be greater than approximately £100M.

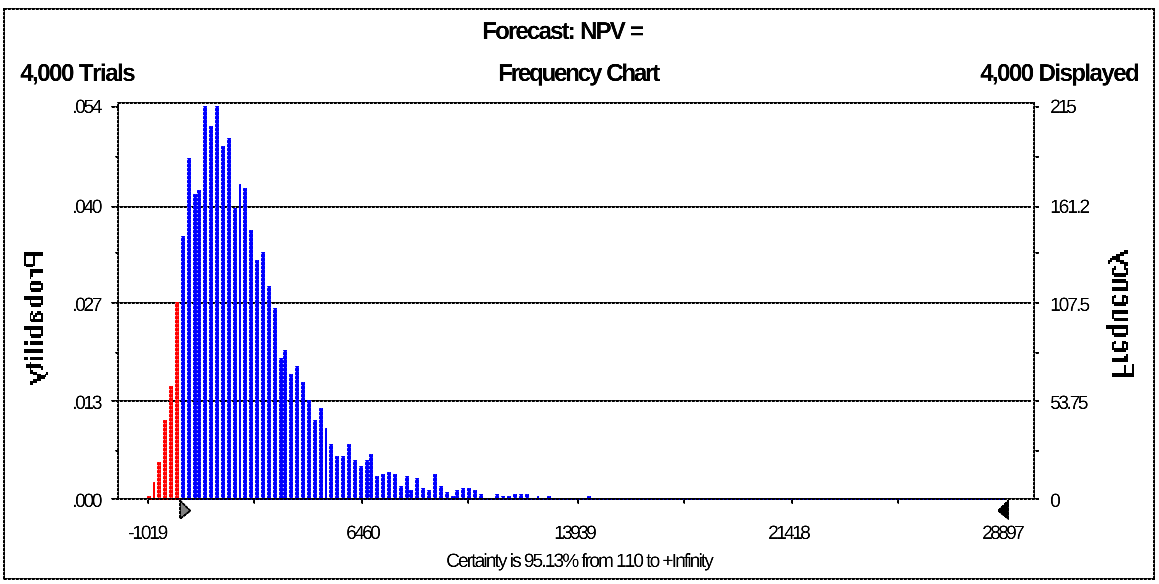

Figure 9 - Histogram of Project NPV

Assuming optimistically that flexibility is worth £500M (recall that the value of flexibility will rise as the value of the underlying market rises) we can also observe that there is only a 20% chance that the project will achieve positive NPV (or have a value of £4.4B - £500M.) Clearly, by these measures of risk and uncertainty (which, again, is likely only a small fraction of all uncertainty), the amount bid does not appear to be justifiable from a risk and reward standpoint.

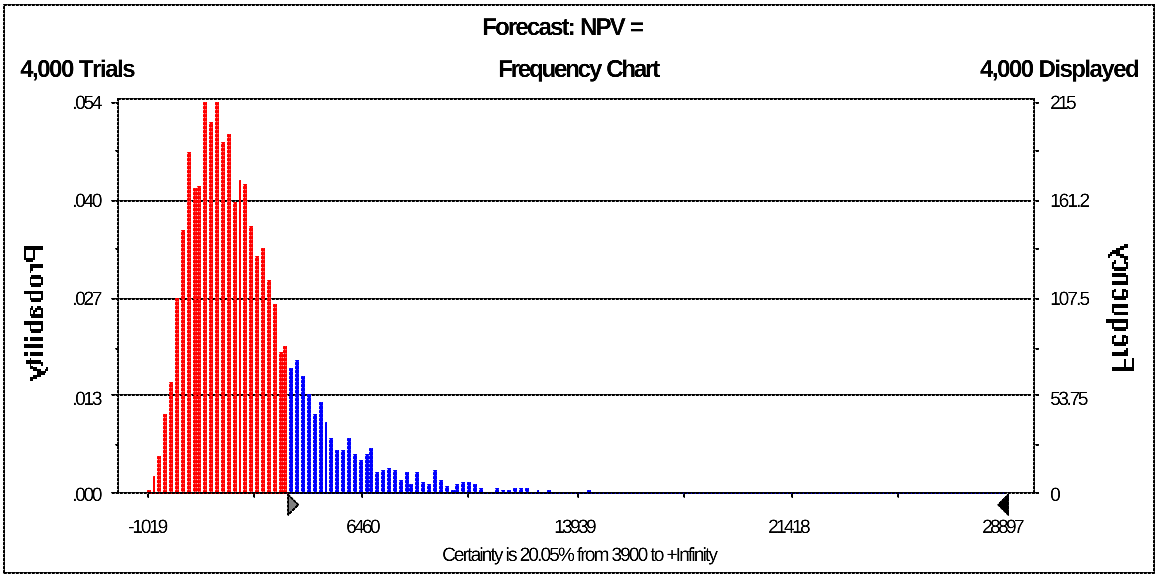

Figure 10 - Histogram of Project NPV Assuming a 500 Pound Value of Flexibility

Keep in mind that, as we underestimated uncertainty, we likely also underestimated that amount of variance in the rate of return of the project. Recall that this value of sigma was used to construct our event tree, and was positively correlated to option value. As a higher sigma could have increased option value to a point where it would make up the present value "gap" between project value without flexibility and the amount bid, it could be useful to determine the value of sigma that would be necessary to achieve flexibility value necessary to achieve a positive NPV for the project.

As the Figure 11 shows, a sigma value of approximately 160% is required to provide enough flexibility value (£1.8B) to provide a positive net present value, although the curve flattens out significantly at sigma values of 100% or above. Again, even with our current underestimation of volatility, 160% seems to be a value that is unlikely to be realized. Again, our information indicates that the price paid for the license cannot be rationally justified on economic grounds.

So we can now conclude that even with flexibility and the risk associated with uncertainty taken into account, that TIW overpaid for License A in the UK 3G spectrum license auction. There are various potential reasons for this overpayment that could be examined via further research. First, the prices paid could be the result of a speculative bubble. Indeed, early

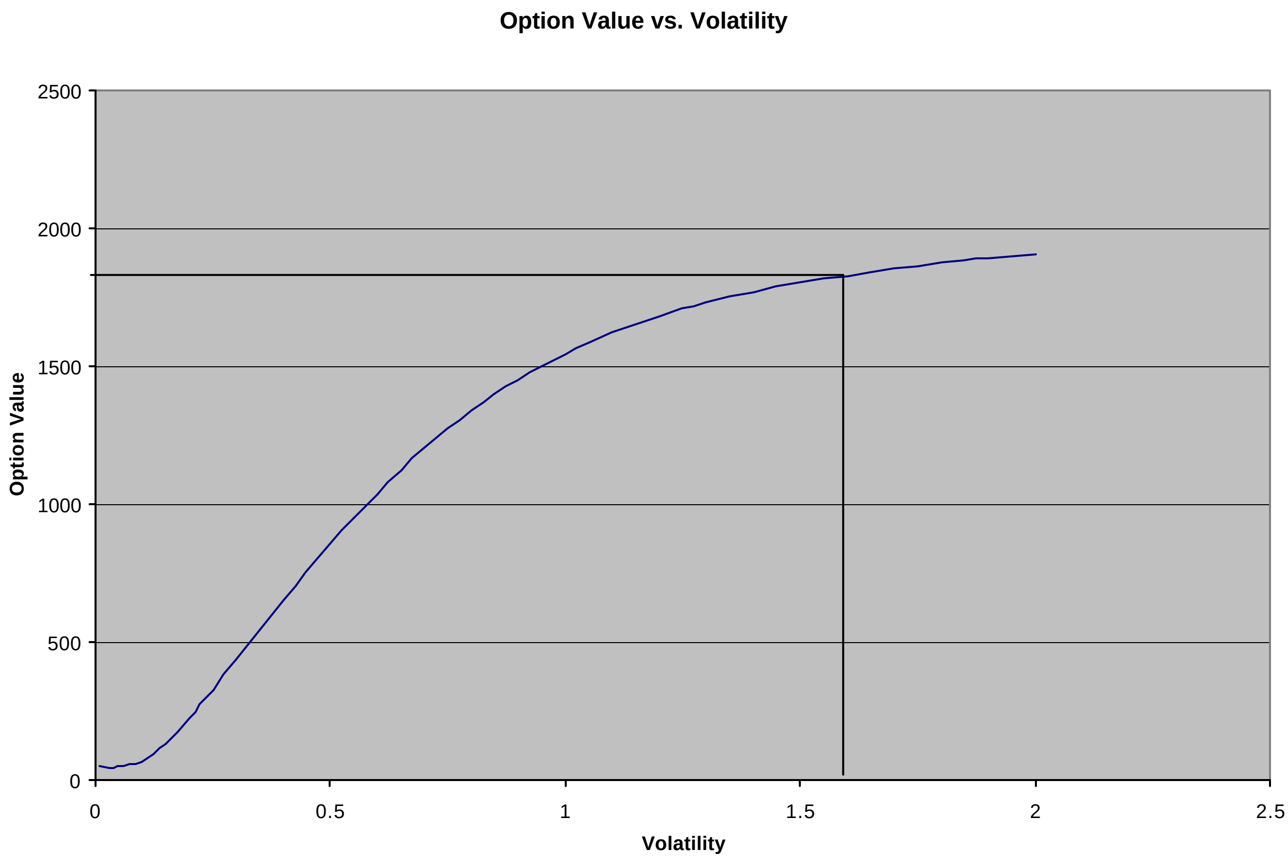

Figure 11 - Impact of Option Value from Varying Volatility Rates

2000 was the peak of the worldwide technology bubble, and the aspirations and hopes for the profitability of 3G could have been caught up in this. Second, our analysis does not take into account strategic value of the option, or the value of synergies with a bidder's existing businesses. For example, a key competitive advantage for wireless companies could be ownership of a worldwide network in order to avoid costly roaming agreements with wireless companies in countries where the carrier doesn't have a presence. In seeking such an advantage, there would be strategic value in ownership of a network in the UK. This would definitely be true for TIW, who, at the time of bidding, was backed by Hutchison Whampoa, a Hong Kong based conglomerate with wireless interests worldwide.

According to our conversation with one of the principal auction participants for BT Wireless, real options were not explicitly used as a valuation technique in preparation for the auction. It seems that uncertainty and flexibility were considered using traditional methods such as sensitivity analysis. However, the absence of ROA from the toolkit of these managers shows the infancy of this decision making technique among most corporations today.

Lessons for Managers

The first step in the Real Option Analysis provided an estimate for the value of the project given discrete expectations through a discounted cash flow model. Applying Monte Carlo analysis to that DCF provided an understanding of the fluctuation in the value of the project given uncertainty in the underlying variables. This understanding has two important benefits for telecom managers. First, the Monte Carlo analysis enables the manager to better understand the risks inherent in the project. Second, knowing the variability in the value of the project has important implications for the optimal capital structure of the firm. If the Monte Carlo analysis reveals that the value of the firm is relatively certain and is highly unlikely to fall below a certain point, then the manager can use inexpensive debt to finance the majority of the project. On the other extreme, if the manager finds that the value of the project is extremely volatile, he should focus on equity financing to reduce the probability and expected cost of financial distress.

The final step, which is to model and value the real options inherent in the project, has two primary benefits. First, it enables managers to better understand the true value of the license, which we already discussed. Second, Real Options Analysis can also be used to provide insights that will help managers structure their decision making so as to extract the maximum value from the license. As described in the introduction, the main lever available to managers is the decision of when and if to expand 1) the geographic coverage, and 2) the capacity to support incremental non-voice capabilities. We have assumed that these options will be exercised concurrently, both to pare the analysis down to simple, easily understandable factors and because both of these options commit the managers to a more aggressive, capital-intensive strategy. Accordingly, we will focus on the decision to exercise this option as the primary real option, or source of managerial flexibility, available to the manager..

We will focus on two approaches for extracting relevant and actionable lessons from the Real Options Analysis. First, we will analyze the impact of varying levels of volatility in the underlying asset and create maps clearly illustrating the manager's optimal option exercise strategy. Second, we will use scenario analysis techniques to model different states of the world, particularly related to the uncertain and important incremental non-voice revenues. Again, we will create maps showing managers how to respond to these different conditions.

The first step in using Real Options Analysis to provide managerial insights is to better understand the key factors driving the decision of when to exercise the option. For financial options in which the underlying asset does not pay out dividends, the option should be exercised at its expiration, regardless of whether it is a European or an American option. However, the underlying asset of the 3G market pays out dividends, indicating that there is an advantage in exercising early to increase the amount of these dividends through expansion. In addition, in contrast to most financial options that are derivatives of long lived securities such as stocks, the 3G license has a finite duration of 20 years. These two factors create a tension in the optimal point for exercising the option, between capturing the profits from exercising the option and reducing uncertainty through more experience with the market. While numerous factors contribute to this balance, we will focus on two key drivers: the level of uncertainty and the amount of incremental non-voice revenues.

The level of uncertainty is a driver that is central to the value of the option. Because the option provides the right, but not the obligation to exercise the option, its owner can wait to gain information about the state of the project and, in the event of favorable outcomes, exercise the option and capture the project's upside while not exercising it in the event of negative outcomes, thereby avoiding the negative returns. This ability to gain information about the value of the project over time and pursue a contingent investment strategy provides the option holder with value. At the same time, the option holder must realize that, with highly uncertain projects, an initially favorable state can quickly deteriorate into an unfavorable one. Accordingly, a higher level of uncertainty should spur the option holder to wait longer before exercising the option.

The following charts show the optimal decision making path for a states of varying uncertainty. There are three potential decisions and, therefore, regions in each graph. First, for some given year-NPV combinations of the project, the option holder should exercise immediately. These areas are shaded yellow. In areas shaded purple, they should wait and proceed to the next period without exercising the option in an effort to resolve uncertainty. In areas shaded blue option holder should abandon the project for a fixed price of £1B.

In Figure 12, where uncertainty is essentially zero, there are only two choices: to exercise or wait.

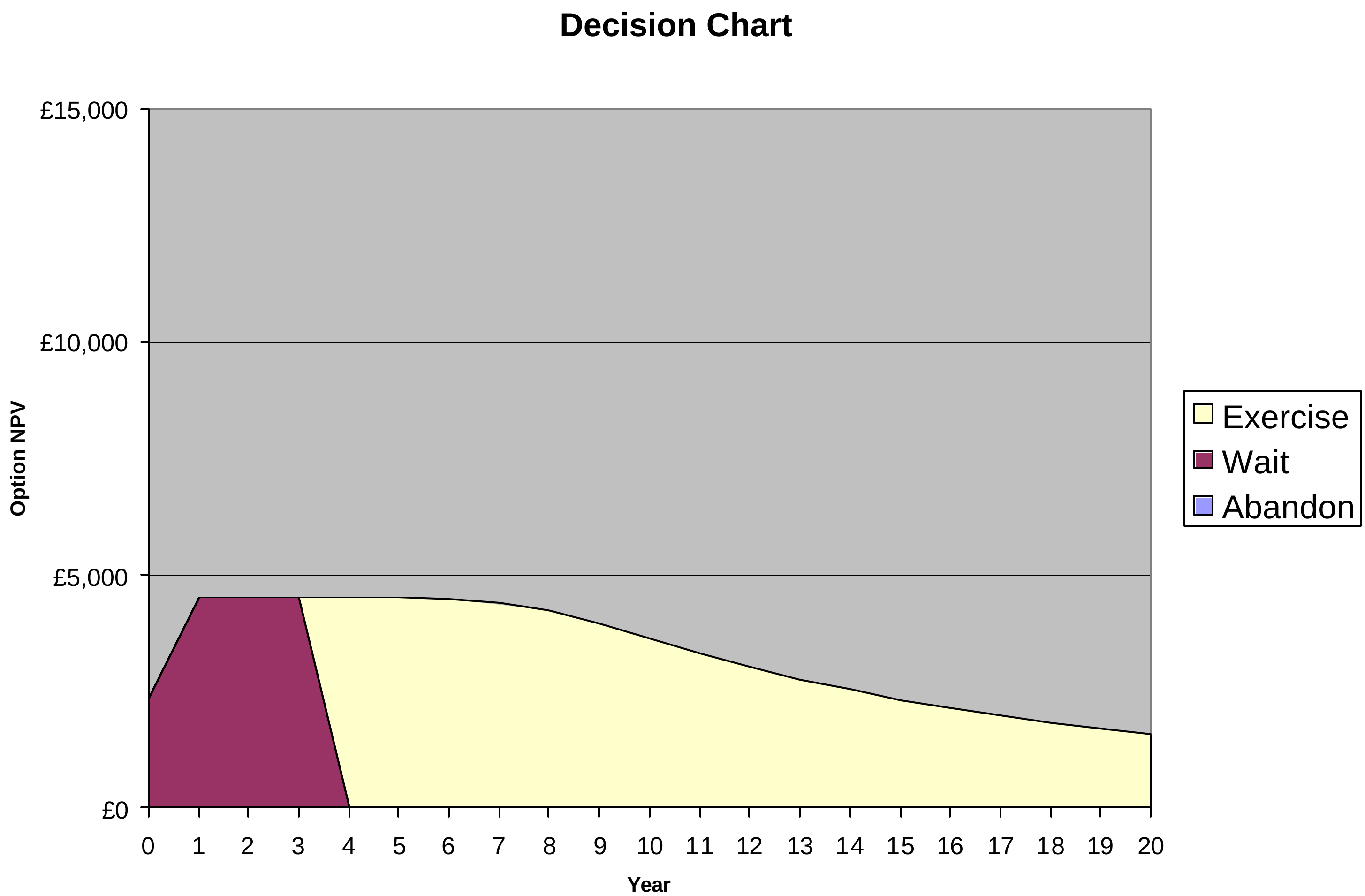

Figure 12 - Decision Graph Given 0% Volatility

The first several years are needed to build out the network and customers begin appearing in year 4. Accordingly, prior to that point, there is no incentive to spend additional capital to increase the geographic breadth or revenue levels of the customer since there are no customers yet. In year 4, because of the very small uncertainty about the future of the market, the manager should exercise the option in almost every scenario. Only in the worst case would the manager wait for the uncertainty to resolve itself, and then would exercise in the following year. Because the manager has already exercised the option and it cannot be reversed, the manager has committed himself to the project, which is appropriate because it will certainly have a positive NPV. Because the optimal exercise point is always year 5, there is no value in being able to wait, learn more about the market, and then make a conditional investment. Accordingly, the option holds no value.

As the level of uncertainty increases, the decision becomes more complex. The following 3 scenarios show increasing levels of uncertainty and the consequent impact on the optimal decision making patterns for exercising the option.

For the first scenario (Figure 13), we will evaluate the decision making process if the volatility increases to 10%, which is still a relatively low level of uncertainty, and is roughly the amount of volatility predicted by our Real Options Analysis. As opposed to the previous situation with no uncertainty and in which the managers always exercised the option in year 5, the relatively low 10% volatility already changes the optimal option exercise point depending on the state of the market.

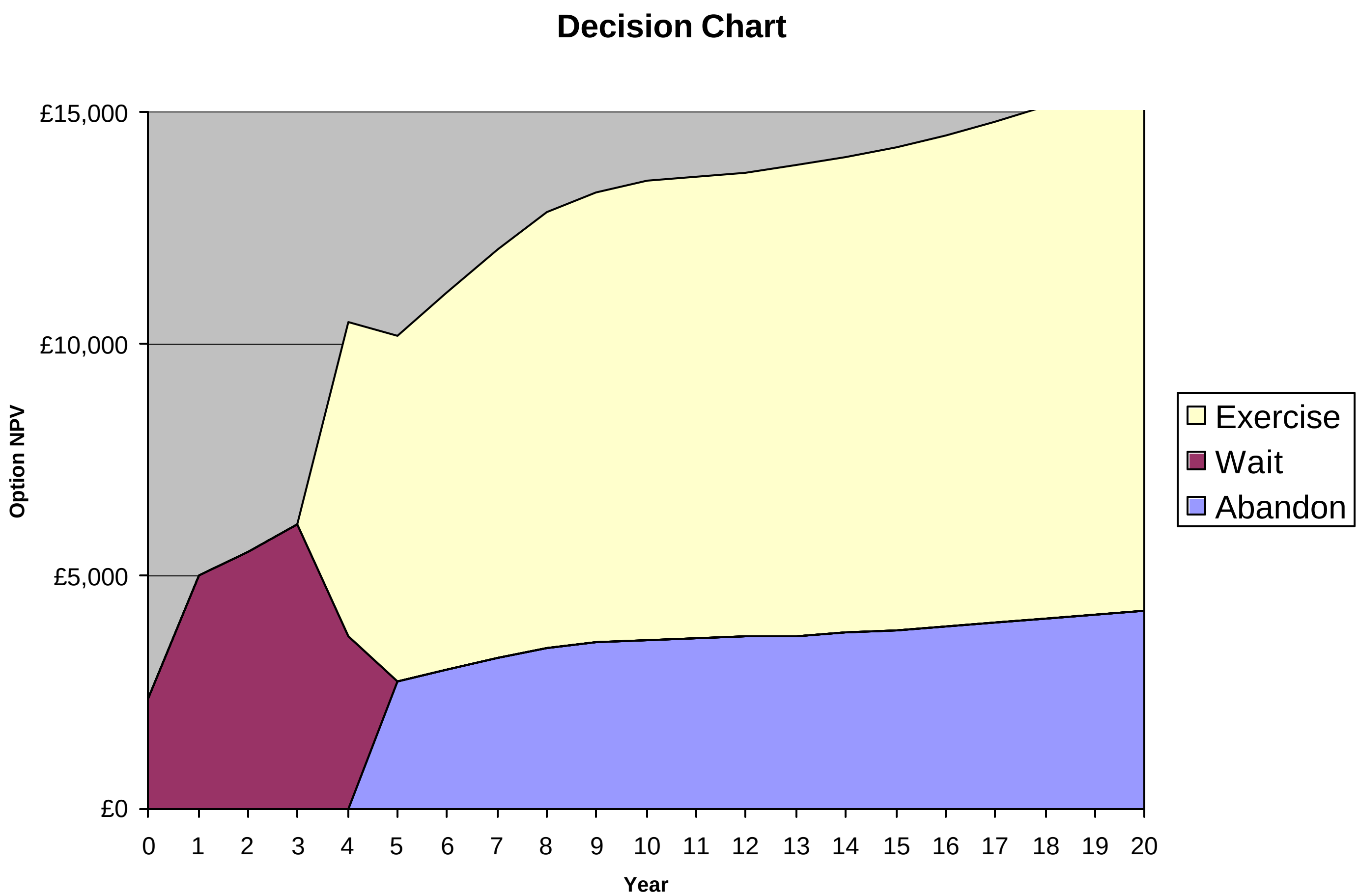

Figure 13 - Decision Graph Given 10% Volatility

If the market is in the most favorable condition and the present value of the project reaches £4,500M in year 4, then the manager should exercise the option in that year. In most situations, where the value of the project is below £4,500 but above £2,000M, the manager should exercise in year 5, as they would if there was no variability in market conditions. In the event of extremely unfavorable market conditions where the NPV of the project falls to £2,000M or below, the manager should abandon the option and restrict themselves to the minimum level of investment. This small increase in the uncertainty increased the number of potential futures facing the manager, and therefore created value in the ability of the manager to react in different ways to these different conditions. For this 10% level of variability, the option value increases to £69M, still a small fraction of the license cost ranging in the billions of pounds. It is important to note, however, that the model is limited to annual decision making periods and that smaller increments would likely be more sensitive to low levels of variability. This would provide a more accurate value of the option at lower levels of variability, which would affect these smaller decision periods to a greater extent than large, annual periods.

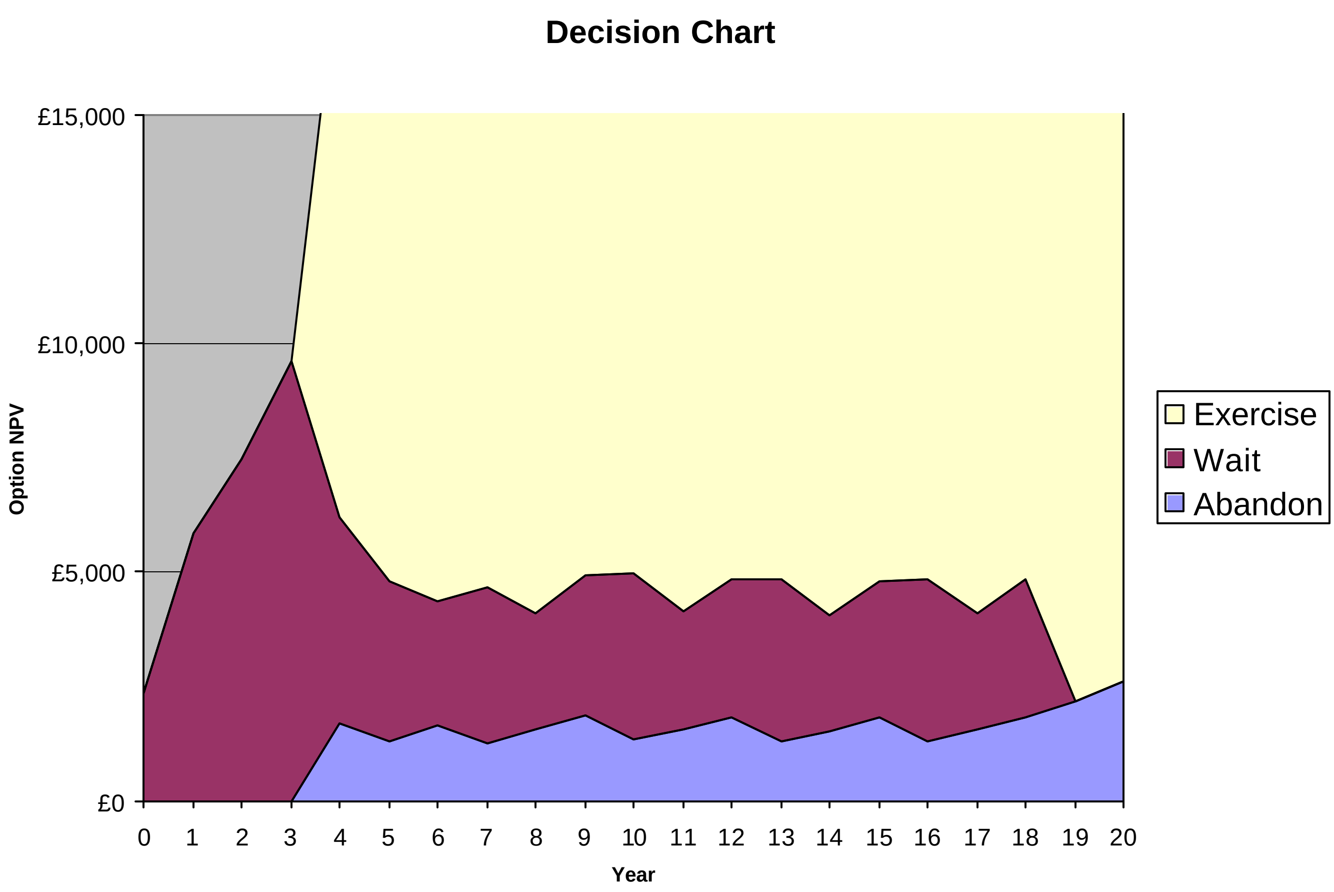

Figure 6 - Decision Graph Given 25% Volatility

As the level of uncertainty increases to 25% (Figure 14), we see a large jump in the value of the option to £329M. As expected, this increase in value is caused by significant changes in the optimal option exercise strategy over time based on the market value. For the first time and for a specific range of market outcomes, we see an optimal wait and see strategy extend itself past the first five periods to almost the end of the license duration. This strategy of waiting is caused by the uncertainty about the future outcome of this increasingly variable market. The option holder should wait until the value of the project more clearly emerges as favorable or unfavorable. While the market value of the license ranges from £1,500M to £4,000M, depending on the period, the option holder should wait until the market value of the license exceeds that range or falls below it, and exercise or abandon the license at that point. As expected, the band for the optimal waiting strategy narrows over time as the final period approaches and the remaining uncertainty decreases.

As expected, further increases in the volatility of the project amplify these effects, as the band where waiting is the optimal decision making strategy expands and the value of the option increases. An increase in the volatility from 25% to 40% almost doubles the option value from £329M to £650M. Tripling the volatility from 25% to 75% almost quadruples the option value from £329M to £1,272M. This gain in value is based on the ability of the manager to learn more about the market outcome before exercising the option, thereby capturing the expanding upside while avoiding the unfavorable outcomes.

In addition to determining optimal option exercise strategies for different volatility levels, this real options analysis can also help decision makers when they face different scenarios of non-voice revenue levels. It would be helpful for them to know what their best strategy would be if non-voice base and incremental ARPUs were only 10% of the initial voice ARPU of £30 instead of the anticipated 20%. Similarly, what should they do these non-voice ARPU levels exceed expectations and reach 30% of the £30 voice ARPU level instead?

Figure 15 shows the optimal option exercise strategy in the unfavorable event that base and incremental non-voice ARPUs are only 10% of voice ARPUs or £3 per month. It illustrates that the low revenue potential for these services dooms the economics to be unfavorable at every point. Even in the most favorable state, the investments required to exercise the option would yield a return lower than the cost of capital and the option should not be exercised in that scenario.

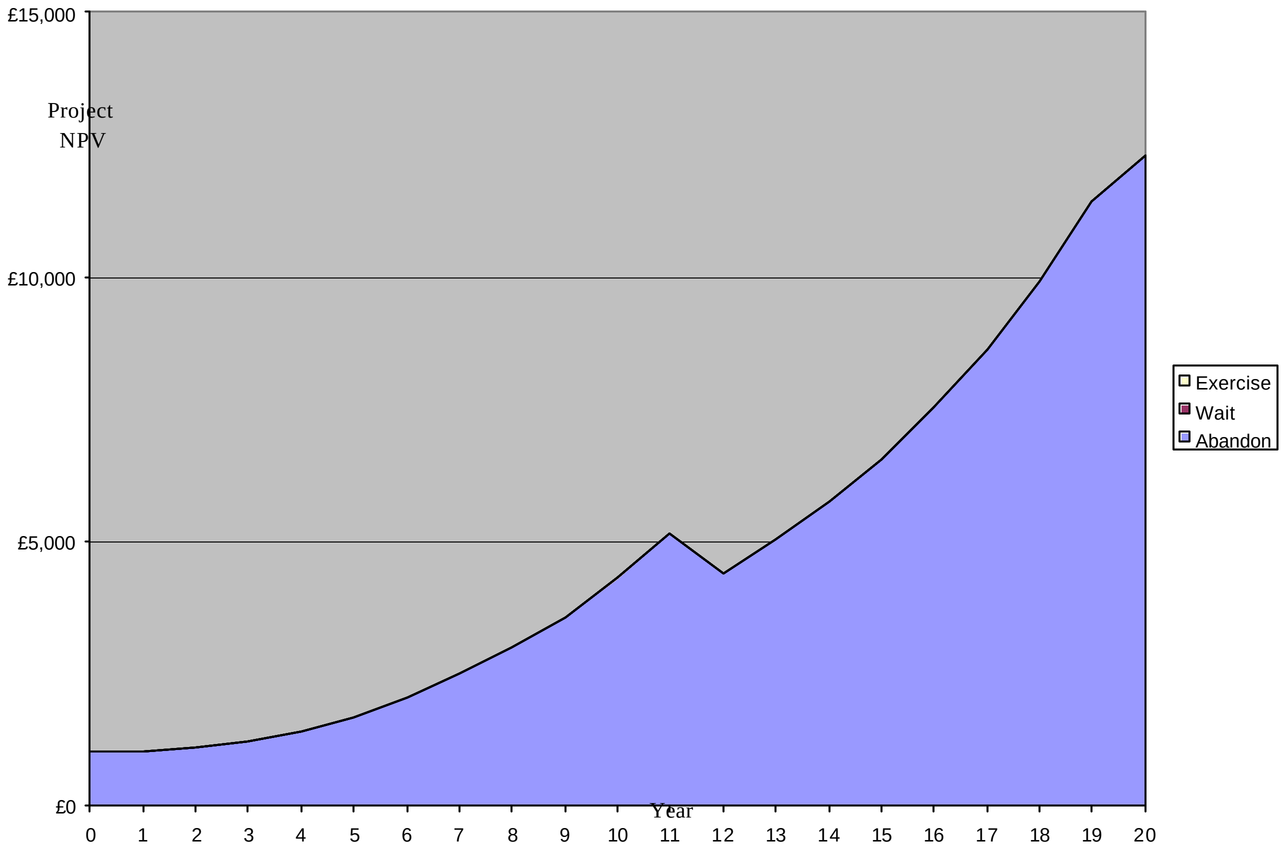

Figure 7 - Decision Graph if Nov-Voice ARPUs are 10% of Voice ARPUs

Reverting to the expected case of base and incremental non-voice ARPUs of 20% of voice ARPU levels, or £6 per month, provides a decision making pattern that is much more favorable to the manager (Figure 16). In the first 7 periods, the manager should wait to exercise the option if the value of the project is below a certain band, usually £5,000 to £6,000. If the value of the license is above that level in those periods or above a band starting at £2,500 in period 7 and rising steadily to £4,000, then the manager should exercise the option.

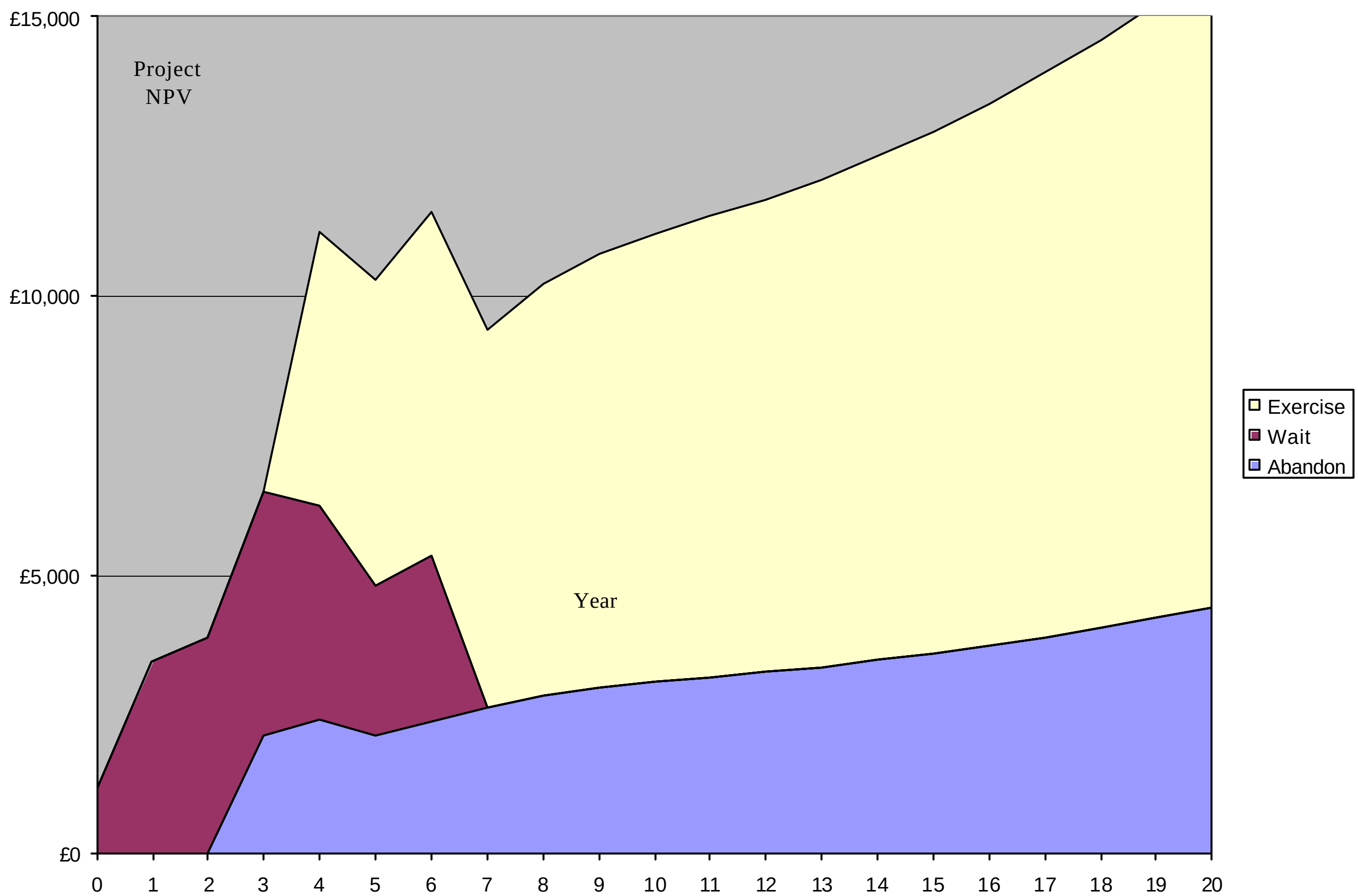

Figure 16 - Decision Graph if Nov-Voice ARPUs are 20% of Voice ARPUs

In the final scenario, the level of base and incremental non-voice ARPUs are 30% of the £30 per month voice ARPUs. In this case, the revenues are so favorable that the option holder should exercise immediately and begin capturing the strong returns of the option. Figure 17 shows the impact of the increase in this initial non-voice ARPUs.

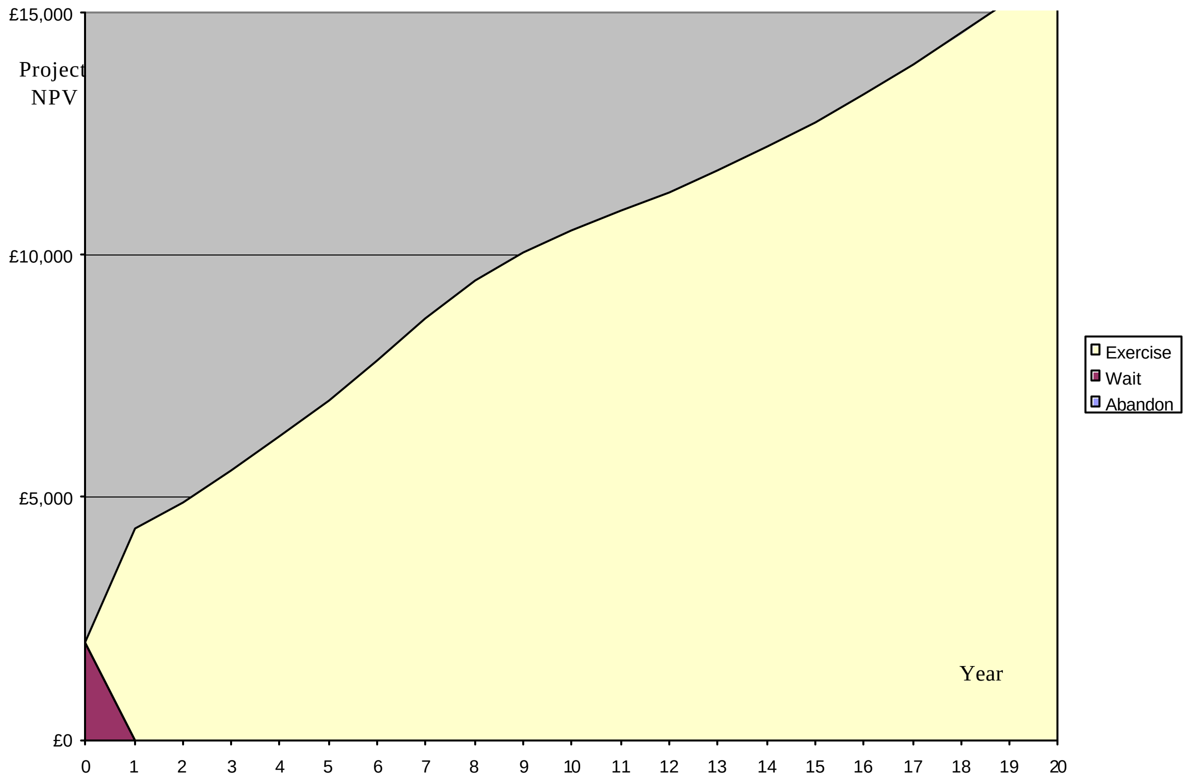

Figure 17 - Decision Graph if Nov-Voice ARPUs are 30% of Voice ARPUs

Appendix A- Real Option Analysis- A More Detailed Treatment

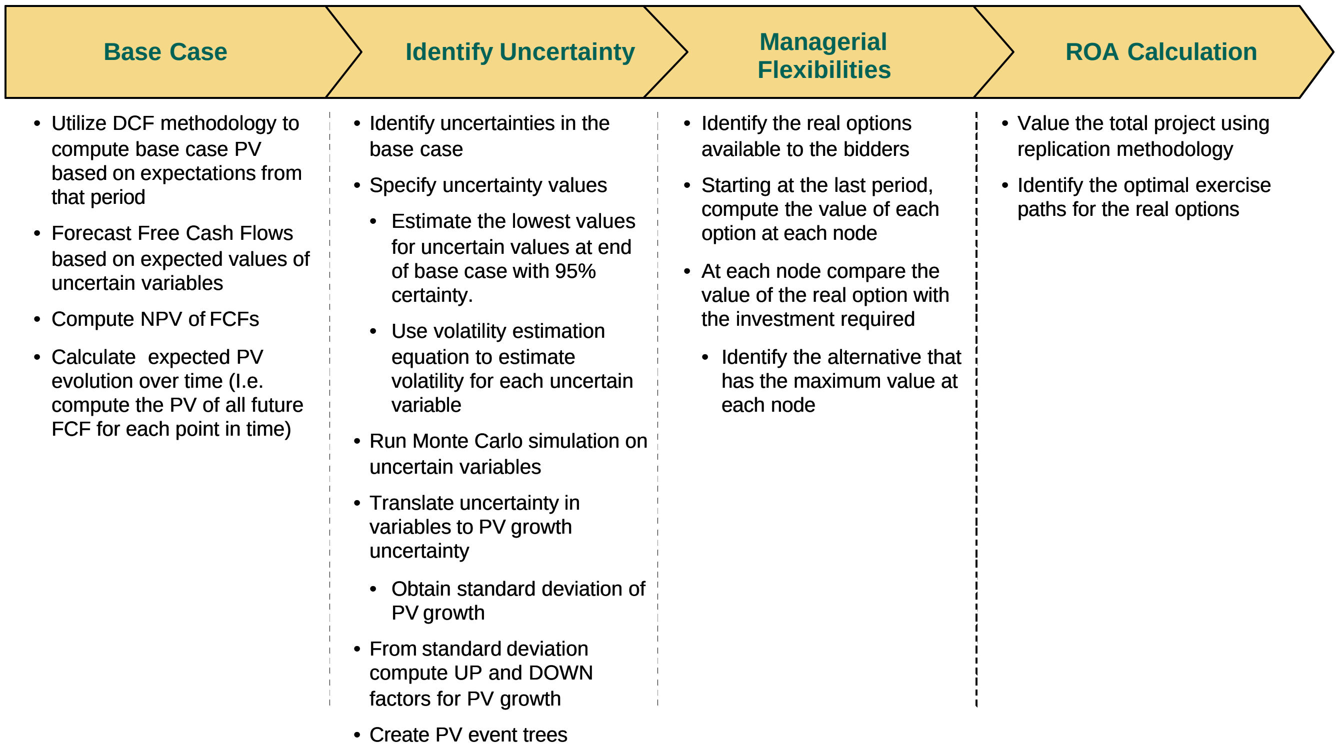

Figure 88 - Four Step Real Option Methodology

The Copeland and Antikarov Methodology for Real Options Analysis (ROA) is made up of four steps, illustrated in Figure 18.

Step 1 consists of the creation of a "base case" discounted cash flow model for the project in question. This base case does not model uncertainty in any of the underlying variables, and does not model flexibility. A Net Present Value (NPV) for the project is computed for the starting point in time (e.g. t_0). Additionally, the evolution of the present value of the project over time needs to be understood. In the case of our analysis, for example, the presence of dividends and the finite life of the project (e.g. 20 years) meant that the present value of the project changed from time period to time period as dividends were paid out and as the end of the project approached. A sample of this evolution is shown in Figure 19 below. As more money is put into the project at time zero, for example (essentially a "negative" dividend) the post dividend value of the project jumps from £2.355B to £4.533B, as the present value of the future cash flows no longer has the large negative value to "drag it down."

	0	1	2	3	4	5
PV Ex Div	2,355	4,918	5,336	5,790	6,276	6,780
Dividend	(2,177.64)	-	-	5.66	27.29	71.30
PV Post Div	4,533	4,918	5,336	5,784	6,249	6,708
Div % of Value	-92%	0%	0%	0.0978%	0%	1%

Figure 99 - Sample Evolution of Cash Flows for New Entrant

Step 2 involves the identification and modeling of uncertainty in the underlying asset. Monte Carlo simulation is then used to estimate the volatility of the rate of return of the project, which is a key driver of the options analysis in Step 3.

Copeland and Antikarov advocate a fairly systematic and specific method for defining the parameters of the uncertainty, involving the estimation of 95% confidence interval values for the upper or lower bound of parameters, and the use of an estimation equation to arrive at volatility. Our methodology, however, involved a combination of different tactics. To model uncertainty in the growth rate of Average Revenue Per User, for example, we approximated ARPU values using geometric Brownian motion, represented by:

$$A_t = A_{t-1}\ e^{(?????\ \wedge??????\ t?????\mathrm{sqrt}(?\ t??Z\}}$$

where A_t and A_{t-1} the ARPUs at times t and t-1, respectively, ? is the growth rate, ? is the baseline variability, or sigma, in the growth rate, and Z is a normally distributed random variable with mean=0 and standard deviation =1. For a baseline sigma, we chose a value of 20%. For another uncertain variable, the Bass Model parameters of p and q that were used to model subscriber growth, we used an assortment of different tactics to model uncertainty. We were able to determine that the subscriber growth curve used in the Dresdner report, (one of our key background resources) corresponded to a p of .031, and a q of .562. This led to the following curve:

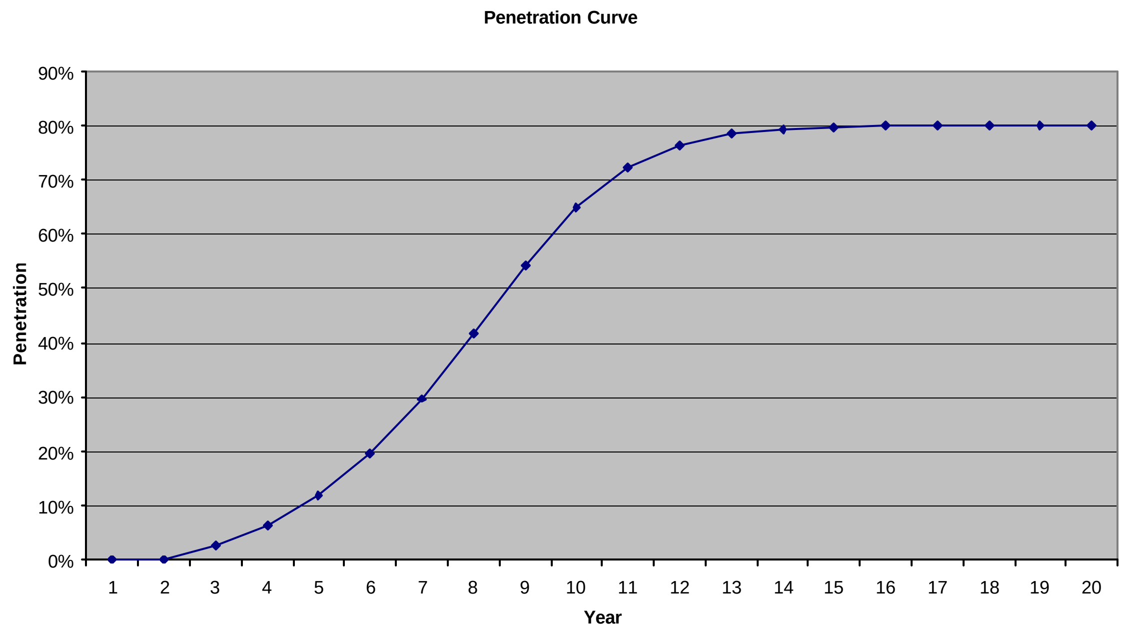

Figure 20 - Graph of Penetration Curve Forecasted by Bass Model

However, as a baseline, this curve appeared to be overly pessimistic. As far as the value for p, which indicates how quickly the innovation is initially adopted by the population, it appeared especially conservative, especially considering the fact that 3G companies who already have 2G customers would be able to "upgrade" these customers to the more advanced network with special promotional deals, handset subsidies, etc. In short, it appeared likely that there would be more than 20% penetration by Year 6.

We also considered historical data to attempt to fit our curves.

Product/Technology	Initial Trial Probability (p)	Diffusion Rate Parameter (q)
B&W TV	0.028	0.25
Color TV	0.005	0.84
Air conditioners	0.010	0.42
Clothes dryers	0.017	0.36
Water softeners	0.018	0.30
Record players	0.025	0.65
Cellular telephones	0.004	1.76
Steam irons	0.029	0.33
Motels	0.007	0.36
McDonalds fast food	0.018	0.54
Hybrid corn	0.039	1.01
Electric blankets	0.006	0.24
A study by Sultan, Farley, and Lehmann in 1990 suggests an average value of 0.03 for p and an average value of 0.38 for q.		
Source: David Berkowitz, University of Alabama at Huntsville		

Figure 21 - Chart of Penetration Curve Forecasted by Bass Model

As the Figure 21, the p value for cellular phone adoption (we assume this refers to 1G analog networks) was .004, while the q value was an extraordinarily high 1.76. In our case, this would have yielded the following curve:

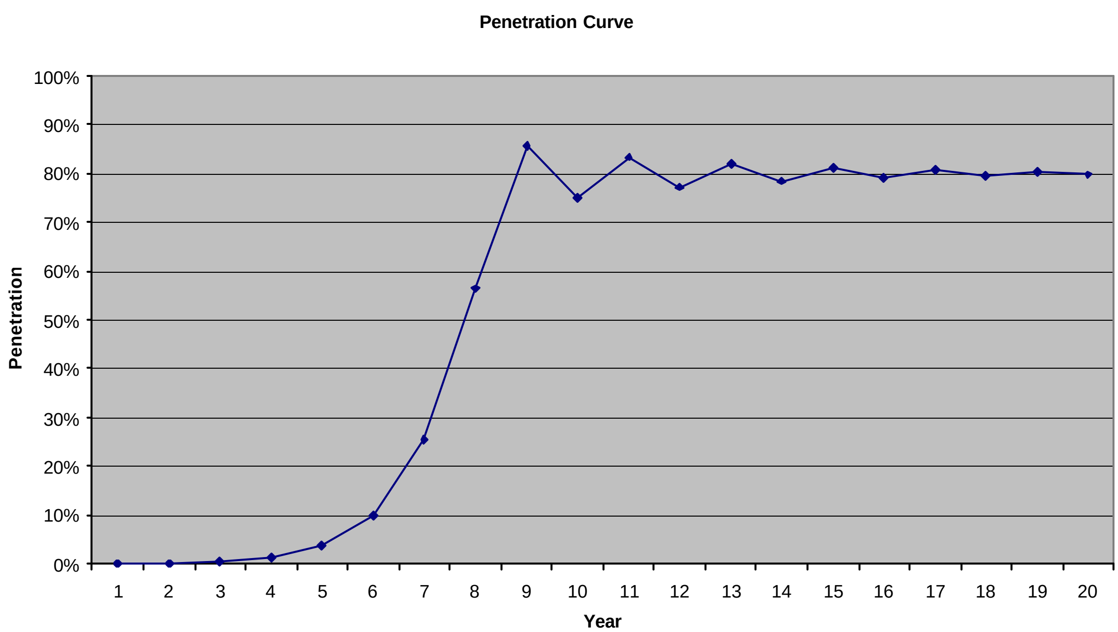

Figure 22 - Graph of Penetration Curve Forecasted by Bass Model Given p = .004 and q = 1.76

These values appear to be even more different from what we might expect to see. Again, we can especially expect to see a p value much higher in scope, as users will already be familiar with the basic lifestyle and usage patterns of wireless phones.

We estimated that the correct mean values would have a higher p-value than the ones in the previous examples, as well as a q-value somewhere in between .562 and 1.76. We ultimately decided to model uncertainty in subscriber growth using a triangular distribution for p and q. The appropriate values were as follows:

	Min Value	**Likeliest**	**Max**
P	.03	.065	.1
Q	.5	.85	1.2

Figure 10 - Chart of Likely P and Q Values for the Bass Model

Graphically, the possible ranges for the penetration curve appear as follows:

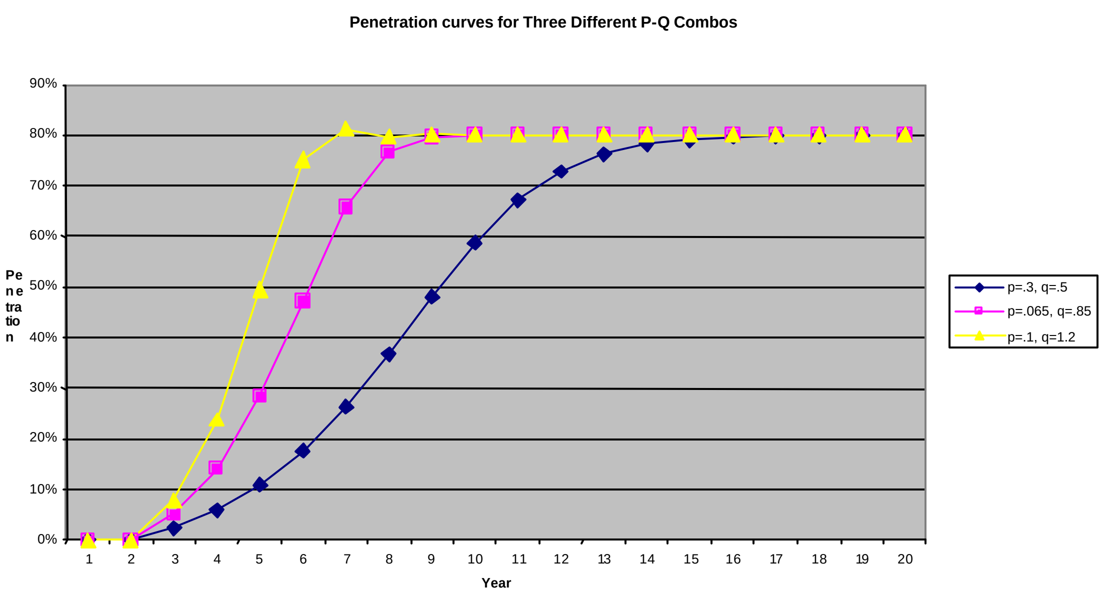

Figure 24 - Likely Penetration Curves Predicted by Bass Model

Once uncertainty in the underlying variables is quantified, Monte Carlo simulation is used to distill that uncertainty into a single measure of uncertainty for the business case: that of the standard deviation of the rate of return of the project. The rate of return for the project was defined by: Z= ln(PV1 + FCF1 / E0[PV0]) where PV1 is the present value of the remaining cash flows of the project from t=2 to the end of the project (e.g. the present value at time 1), FCF1 is the cash flow at time 1, and E0[PV0] is the expected present value of the remaining cash flows of the project from t=1 until the end of the project, fixed prior to the initiation of the Monte Carlo simulation. (Otherwise the rate of return is constant and equal to the discount rate!) As discussed in the body of the text, a value of 12% was found as the standard deviation of the rate of return.

The standard deviation of the rate of return is then used to calculate the UP and DOWN factors that make up a binomial event tree. The UP factor is defined as $U=e^{(?\ SQRT(?\ t))}$ where sigma is the annual volatility of the rate of return, T is the length of the horizon, n is the number of time steps, and ? t = T/n. D is defined simply as 1/U.

Building the binomial event tree is straightforward, except that we must deal with the special case of an underlying asset that pays out dividends. In other words, the present value of the project drops at each point in time as a dividend is paid out (or increases as a negative dividend is bypassed.) In order to maintain the recombining nature of the binomial event tree, it is necessary to make the dividends a constant proportion of the project value at any point in time, regardless of whether or not it is in an up state or a down state. In order to determine these percentages we computed the present value and dividends (cash flows) for our base case project at every point in time. We then took these dividend percentages and applied them as fixed at each particular time period in the event tree. Portions of both the ex-dividend and post-dividend event trees, as well as the dividend cash flow percentages that link the two, are shown in the figure below.

	0	1	2	3
PV Ex Div	2,355	4,918	5,336	5,790
Dividend	(2,177.64)	-	-	5.66
PV Post Div	4,533	4,918	5,336	5,784
Div % of Value	-92%	0%	0%	0.0978%

Ex Dividend

	0	1	2	3
0	2355	5111	5762	6497
1		4020	4533	5111
2			3566	4020
3				3162

Post Dividend

	0	1	2	3
0	4533	5111	5762	6491
1		4020	4533	5106
2			3566	4016
3				3159

Figure 25 – Sample of Ex and Post Dividend Event Trees

Once the event tree has been constructed using the appropriate volatility value, it is necessary to conduct the option valuation. This encompasses steps 3 and 4. By this point we had chosen the types of flexibility (expansion and abandonment) that we were going to model. The risk-neutral probability method of option valuation (as opposed to the replication method listed in Figure 18) was used to model the two options that we examined. In the cells for corresponding to the event tree's possible states of nature in period 20, the final period, a payoff function was modeled as follows: MAX (0, Expand, Abandon). In other words, in the final period, the manager will choose the greatest of either not exercising, and gaining nothing, exercising the expansion option and gaining a certain amount of incremental revenue (equal to the % increase in the value of the project times the value of the project minus the strike price) or of abandoning the project and gaining the fixed price of abandonment.

In the interior cells of the event tree, the manager is faced with the following payoff function: MAX (Wait, Expand, Abandon). The calculation for expansion and abandonment is the same as above. In years other than the last year, however, these must be compared against the value of waiting. According to the risk-neutral probability method, the value of waiting, or of holding an option at any point in time, is given by: $C_o = [pC_u + qC_d] / (1 + r_f)$ where C_u is the value of the call in the up state (e.g. for any period 19 cell this is the corresponding up-state cell in period 20), C_d is the value of the call in the down state, p and q are the "risk neutral" probabilities which allow the option to be calculated using the risk-free method (where q = 1-p), and r_f is the risk-free rate. Using this method, the event tree is solved at the time 0, or the initial node. As a final step, we must subtract the difference between the project value of exercising in the optimal year of 2003 and the project value in the case in which the option is never exercised. So,

Value of option = Event Tree Year 0 Value – (Optimal Project PV – Base Case Project PV)

Based on the results of this exercise, we created tables indicating the optimal exercise paths for management in various states of nature. A piece of sample output is shown in Figure 25 (note that "A" indicates abandon, "E" indicates Exercise, and "W" indicates Wait.

	0	1	2	3	4	5	6
0	W	W	W	W	E		
1		W	W	W	E		
2			W	W	E		
3				W	W	E	
4					W	W	E
5						A	A

Figure 26 - Sample of Decision Matrix

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