Estimation of the "Intra Migration Option Value" for eircom

Prepared for eircom

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1 Executive Summary

This document estimates the value of the option of Other Authorized Operators (OAOs) to switch from bitstream to full LLU, or 'migrate' from one eircom wholesale service to another. This switching could involve significant sunk investment costs for eircom as the former involves investment in equipment which is partially specific to the task of bitstream access, while full LLU would involve more investment by the OAO. The regulator, ComReg, has effectively accepted that there is an economic logic in charging a migration fee to reflect the free put[1] option to switch that eircom is effectively giving OAOs.

Indecon has estimated the value of this option using standard option valuation techniques and various estimates of the necessary parameter inputs.

[1] The option is a 'put' because effectively the OAO makes eircom take assets for which the only value to eircom is in the provision of the bitstream service.

The estimated value of the option is [redacted]. The main parameters of the option value are: the strike price (value of the sunk investment), current value of the underlying asset (value of a bitstream customer relative to an LLU customer), the time to maturity, the risk free rate, and the volatility. The option price is potentially sensitive to factors which influence the values which these parameters take. However, empirically, the valuation here is sensitive to the value of the sunk investment (strike price) and the value of a bitstream customer to an OAO relative to an LLU customer (the current value of the underlying asset). The strike price is sensitive to the redeployment costs and the equipment costs. The option price is also somewhat sensitive to the time between the bitstream contract initiation and the option price evaluation date. The option value of the put option increases as the value of the sunk investment (strike price) increases. Since the strike price is a function of the depreciated equipment costs, the option value is usually greatest at the inception of the bitstream contract, before the equipment has depreciated. If the OAO migrates very early into the contract, the sunk costs to eircom are greater than if the OAO migrates only after the equipment installed by eircom has substantially depreciated.

2 Introduction

This chapter introduces the main goal of the study, the estimation of the "Intra Migration Option Value"[2]. It explains why the real options methodology provides the correct approach to this task.

2.1 The LLU Migration Option

In order to offer Bitstream Wholesale services to other authorized operators (OAOs), eircom must install expensive equipment (such as DSLAMs) in the telephony exchange centres. According to eircom, some significant equipment higher-up the network from the exchange must also be installed with the scope to handle the additional traffic due to bitstream. By installing this equipment, and also allowing the OAO to switch to local loop unbundling (LLU) services at any future time, eircom effectively gives the OAO an American real put option[3]. If this option is exercised at anytime before expiry (the expiry date corresponds to the time when the bitstream-specific assets are fully depreciated), then eircom is left with sunk costs in the form of bitstream-specific-assets for which it cannot recover the costs. Depending on the costs of deployment and the remaining value the assets, eircom may or may not find it worthwhile to redeploy these assets. If eircom is not compensated for these sunk costs, it is obvious that the OAOs have been given a free put option. The aim of this study is to develop and employ an appropriate method for estimating the value of this put option.

[2] There is also the issue of 'inter' migration, but we do not focus on that here.

[3] We explain more about real options later. An option gives the holder the right, but not the obligation, to buy or sell something at a fixed price. In this case, the option is an "American" because the time to expiration is not fixed. The option is 'real' because it is based on physical or commercial arrangements, rather than a financial contract. A put option gives the holder the right to 'sell' rather than 'buy' an asset. In our case, migration from bitstream and leaving eircom with sunk investments in relation to that service is akin to 'putting' that value back on eircom.

2.2 Real Options: How They Work

This subsection begins by explaining the theory of real options, describing the difference between real and financial options, between European-style and American-style options, and between call and put options. It also clarifies the rationale for treating the LLU migration option as an American-style real put option.

2.2.1 Real Call Options

Real options are flexible uses of real assets rather than financial contracts. Real option methodologies are highly suitable for studying investment decisions that involve high uncertainty, significant costs and irreversibility. Real options theory emerged from the criticism of traditional investment decision rules, such as the net present value (NPV) or discounted cash flow (DCF) method[4]. The NPV rule says that a firm should not invest in a project unless the present value of net cash flows from the project (DCF) is positive. If there is no uncertainty over future cash flows; if the investment is completely reversible; or if there is no possibility of delaying the investment; then this rule is in general correct. However, if the investment is fully or partly irreversible; if there is uncertainty over the future cash flows; or if the investment could be delayed; then the use of this rule in general does not maximize the firm's value (or the value of a particular project). The reason for this is that the NPV rule says that the firm should invest if there will be a positive net return on the investment. The NPV rule does not take into consideration the fact that, unless the investment is a now-or-never proposition, the correct comparison should not be investing today versus never investing, but rather investing today versus waiting, and perhaps (depending on how market conditions turn out) investing at some unspecified time in the future.

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[4] The analogy with a decision to 'invest' is in fact a 'call' option. The decision to abandon a project can be considered a 'put' and this is analogous to what we estimate here, but the literature originally developed with respect to the invest/don't invest decision.

A firm with an opportunity to invest holds a "real option", i.e., it has the right, but not the obligation, to buy (or sell) an asset at some future time of its choosing. This is similar to holding a financial call (or put) option. The only difference is that a real call option gives the owner the right to buy a "real asset", such as a factory or equipment, while a financial option gives the owner the right to buy a financial asset, such as a stock.

When a firm makes irreversible investment expenditure, it exercises its real option to invest. It gives up the possibility of waiting for new information to arrive that might affect the desirability or timing of the expenditure; it cannot disinvest should market conditions change adversely. This lost option value is an opportunity cost that must be included as part of the total cost of the investment, along with the direct investment costs of the equipment (e.g., machines and factories).[5]

2.2.2 Real Put Options

Real put options can also be explained by analogy to their financial counterparts. A European financial put option is a contract between the writer (or seller) and buyer which gives the buyer the right, but not the obligation, to sell the underlying commodity or asset to the writer at a certain time (the expiry date) for a certain price, known as the strike price. An American call option is similar, except that it can be exercised anytime between the inception of the contract and the expiry date.

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[5] Two of the classic references on real options are:

McDonald, R. and D. L. Siegel. 1986. The Value of Waiting to Invest. *Quarterly Journal of Economics* 101: 707 - 728.

Dixit, A. K. and R. S. Pindyck. 1994. *Investment Under Uncertainty*. Princeton University Press

A real American put option, then, gives the holder the right to sell a real asset for a predetermined price (the strike price) at any time before the option expires (the maturity date). As an example of a firm holding a real put option, take the option to abandon a project. Suppose that a firm makes an investment in machines that are standard tools in its particular industry. Those machines can often be resold or shifted to another use if their product doesn't sell well. The price of the resale of the machines is thus a "floor" on the cost of the machines in the particular project. If the firm's DCF is high, it will want to stay in production. However, if demand is sluggish, the firm's DCF may fall below the resale value of the machines (the strike price). In this case, the firm would be better off by selling the machines to another company, or shifting them itself to another use (i.e., exercising the real option). The payoff to the real put option at the time of exercise would be the resale value of the machines less the NPV of the net cashflow from production. The expected payoff to the real put option in the period before exercise would depend on the probability that the DCF of the machines in production would fall significantly below their resale value. In other words, the value of the real put option would depend on the volatility of the underlying asset.

3 Brief Review of Real Options Research in the Telecommunications Sector

In this section, we review the available research on real options and telecommunications. The main purpose of this section is twofold: first, to demonstrate the wide-spread use of the real-options valuation methodology in the telecoms sector; and second, where applicable, to review some of the input parameters to the real options calculation methodology to give benchmarks for estimates of parameters for our models. Most important of these parameters is the volatility. We provide additional details in an Annex to this document.

Numerous studies have used a real options valuation framework to value various aspects of telecommunications networks and operational flexibility within the strategies available with technology going forward. Studies have used a variety of techniques to calculate the value of the real option associated with various investment opportunities in the telecommunications industry. The real options approach has been used to analyse cases involving telephony, broadband, Internet, cable, wireless etc.

For just a few examples, Alleman (1999, 2002a, 200b, 2003) uses the strategic benefits that options offer for issues such as cost modelling, modelling regulatory distortions, and strategic evaluation.[6] Economides (1999) applies real options in studying the economic principles on which cost calculations should be based.[7] Authors in Edelmann, Kylaheiko, Laaksonen and Sandstrom (2002) capture the strategic flexibility offered by real options in understanding the alternatives in the telecommunications industry.[8] Kutailakata and Lin find the investment threshold at which firms are indifferent to investing immediately and postponing the investment.[9] Basili and Fontini (2003) use the Black-Scholes formula to evaluate the aggregate option value of the UK 3G telecom licenses.[10] Herbst and Walz (2001) use the option of abandonment and the growth option to analyze the value of auctioned UMTS (Universal Mobile Telephone System) licenses in Germany.[11]

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[6] Alleman, J. 2003. How should telecom companies be valued? *America's Network* 107: 34-40.

Alleman, J., and P. Rappoport. 2002. Modeling Regulatory Distortions with Real Options. *The Engineering Economist* 47: 390-417.

Alleman, J. and E. Noam. 1999. *Real Options: The New Investment Theory and its Implications for Telecommunications Economics.* Kluwer Academic Publishers.

Alleman, J. (2002). A new view of Telecommunications Economics, *Telecommunications Policy*, 26, 87-92.

[7] Economides, N. 1999. Real Options and the Cost of the Local Telecommunications Network in Alleman and Noam (2002) Op. cit.

[8] Edelmann, J., Kylaheiko, K., Laaksonen, P. and J. Sandstrom. 2002. Facing the Future: Competitive Situation in Telecommunications in Terms of Real Options. *Proceedings of the IAMOT2002 11th International Conference of Management of Technology.*

[9] Kulatilaka, N. and L. Lin. 2004. Strategic Investment in Technology Standards. *8th Annual real options Conference* Montreal, Canada.

[10] Basili , M. and F. Fontini. 2003. The Option Value of the UK 3G Telecom Licenses. *The Journal of Policy, Regulation and Strategy for Telecommunications* 5: 34 – 52.

[11] Herbst, P. and U. Walz. 2001. Real Options Valuation of Highly Uncertain Investments: Are UMTS-Licenses Worth Their Money. Working Paper, Department of Economics, University of Tuebingen, Mohlstr. Working paper available from http://www.wiwi.uni-frankfurt.de/Professoren/walz/umts.pdf

Furthermore, Paxson and Pinto (2004) show that a real options pricing model can offer a means of formulating the timing of the investment in 3G technology by Optimus, a Portuguese telecom operator.[12] D' Halluin, Forsyth & Vetzal, (2002, 2003) apply real options methodology to value wireless network capacity.[13] This involves evaluating American options or option with the possibility of early exercise.

These are just some of the selected examples in the published international literature. More details and reviews are found in the annex. We study volatility and the volatility estimates used existing studies later.

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[12] Paxson, D., and H. Pinto. 2004. Third Generation Mobile Games – An Application of Real Competition Options. *Proceedings of the 8th Annual Real Options Conference*, Montreal, Canada.

[13] D'Halluin, Y., A. P. Forsyth, and R. K. Vetzal. 2002. Managing Capacity for Telecommunications Network Under Uncertainty. *IEEE/ACM Transactions on Networking* 10: 579 – 588.

D'Halluin, Y., A. P. Forsyth, and R. K. Vetzal. 2003. Wireless Network Capacity Investment. *Proceedings of the 7th Annual Real Options Conference*, Washington DC, USA.

4 Modeling the Option Value

This section reviews the methods used to obtain the most reliable estimates of the parameters in the option pricing exercise: volatility, risk free rate, discount rate, time to maturity, value of the underlying asset and strike price. This section also explains the intuition behind the Black-Scholes formula for the value of a put option, and shows how this formula can be adjusted for the possibility of early exercise and deployed to solve the LLU migrations option pricing problem.

4.1 Parameter Estimates

The main parameter inputs to an option are the strike price, the value of the underlying asset, the time to maturity, the risk free rate, and the volatility. Each of these is discussed in detail below.

4.1.1 Strike Price

The strike price is the sunk costs per bitstream customer[14] (such as DSLAMs). The value of the costs which are sunk costs is a function of the net value of redeployment (the value of the asset *in* redeployed must be subtracted from the initial cost of the bitstream assets; the cost of redeployment is added in) per customer and the depreciated value of the bitstream assets per customer, which in turn depends on the equipment costs. The sunk costs are calculated as follows:

$$X = (1-\alpha)d + \alpha(m\Delta d + \delta)$$

where:

[14] We have estimated all these values on a per customer basis because this is analogous to many value in the regulatory space, such as the LLU price.

α = probability that the bitstream assets are redeployed

d = the depreciated value of the bitstream assets per customer

m = the number of months between migration and redeployment

Δd = the monthly change in the depreciated value of the bitstream assets per customer

δ = the cost per customer of redeployment

The first term above represents the value of the assets given migration, weighted by the probability that the assets are not redeployed. The second term is the sum of the redeployment cost (δ) and the value lost through depreciation in the time between migration and redeployment $(m\Delta d + \delta)$, weighted by the probability that the assets are redeployed.

Value of Equipment

Indecon received estimates of equipment costs associated with bitstream from eircom. The values include DSLAM Cards plus ATM/SDH/PDH investment that would be associated with a typical bitstream enabling investment. The values are consistent with the average depreciated values for current assets under the current regulatory accounts according to standard accounting procedures. The following table summarizes this data.

Table 4.1: Equipment cost/strike price

Point in Time	Total Equipment Costs
August 07/08	[redacted]

Source: eircom

Redeployment Costs

Indecon received estimates of the redeployment costs from eircom. It should be noted that this is an estimate of the additional cost of taking assets that are installed for the purposes of enabling bitstream, at both the exchange and backhaul levels, and redeploying them elsewhere on the network. This value is used in arriving at the strike price. The rate of redeployment is assumed to be [redacted]. (The *value* of the redeployed asset is subtracted from the initial investment cost). The following table summarizes this data.

Table 4.2: Redeployment Costs

Point in Time	**Costs in redeployment**
August 2008	[redacted]

Source: eircom

These are the costs to eircom to physically redeploy assets which have been installed to service bitstream customers.

Depreciation between Migration and Redeployment

The number of months between migration and redeployment (m) has been estimated to be [redacted].[15] The amount of depreciation per month (Δd) is assumed to accrue on a straight-line basis and is based on a [redacted] month asset life, consistent with the rest of the asset accounting.

Sunk Cost Per Customer

The parameters outlined above are all inputs to the strike price (X), which is the sunk cost per customer. Plugging these values into the sunk cost formula:

[15] This is an eircom estimate.

$X = (1-\alpha)d + \alpha(m\Delta d + \delta)$, the sunk cost per customer in August 2008 is [redacted]. It is noteworthy to repeat that this is reflective of the average depreciated asset values for the most recently available regulatory accounts.

4.1.2 Price of the Underlying Asset

The price of the underlying is the difference between the present value to an OAO of a bitstream customer and the present value of an LLU customer. Currently, it is estimated that there is in effect little difference between the value of a bitstream customer and an LLU customer to an OAO. Thus, this value is estimated to be close to zero. (In fact, we put a value of €1 in for this as a value close to zero, as the option valuation framework is not defined for zero priced assets.) This may change over time, however, and it is assumed that the value of an LLU customer relative to the bitstream customer grows at 3% per annum (akin to a dividend yield).

4.1.3 Time to Maturity

The maturity date of the real put option is [redacted]. This is the figure currently used as the average life of a Bitstream service for price setting purposes.

4.1.4 Risk Free Rate

The risk free rate is the interest rate that can be obtained by an investor at no risk. It is standard practice among practitioners for option valuation to use the market interest rate on short-dated government bonds denominated in the currency in question (euro). The rate of return on German government bills or the rate at which European banks lend to each other, the Euribor rate, is typically used as the risk free rate for the euro. This study uses an average over the last 12 months of the three-month Euribor rates, which are the rates at which banks in the euro area offer to lend euro funds to other banks. The value of this was [redacted].

4.1.5 Volatility

The volatility of the underlying is a key parameter of the option pricing model. Indecon used three different methods of estimating the volatility, as summarized below:

Table 4.3: Three Estimates of the Volatility

Historical volatility	27%
Implied volatility	37%
Previous Research average	45%

Source: Indecon

Each of these methods is discussed in greater detail in the next subsection.

4.2 Volatility of the Underlying Asset

This subsection is a description of the methods used to estimating the volatility of the underlying, which is the most difficult of the model parameters to ascertain. Three clearly distinct methods of estimation were undertaken: a) the volatility of the returns was estimated directly by using historical stock price data, b) the volatility of returns was estimated indirectly though analysing the actual prices at which a large number of telecom stocks options have been traded, and c) the values used for the volatility parameter in a number of academic studies of option pricing in the telecoms industry were reviewed. These three methods are described in detail below.

4.2.1 Historical Volatility

Indecon undertook its own independent assessment of the historical volatility of the underlying based on analysis of the share prices of two hundred and twenty four telecom companies listed on major stock exchanges around the globe. It is judged that this was a conservative estimate, as we believe it may be likely that this methodology results in an underestimation of the true volatility, due to the fact that most of the companies that are listed on major stock exchanges have large customer bases (and thus should be less volatile in their returns). The larger companies probably do not experience as much fluctuation in returns as the smaller operators. This is because they tend to have a broader and more diverse customer base, and this is conducive to something of a levelling-out effect on demand and, hence, returns.

Understanding how the volatility fits into option valuation starts with a model of the option value, such as the Black-Scholes formula. The starting point for the use of the Black-Scholes formula is the assumption that asset prices are lognormally distributed. This assumption implies that asset price changes (i.e. returns) are normally distributed. The lognormal relative price change is given by the equation:

$$v_j = \ln\left(\frac{S_j}{S_{j-1}}\right)$$

Volatility measures the uncertainty of the returns on the underlying asset. The most common estimate of volatility is the sample standard deviation of returns over some time period. The standard deviation of the asset returns is given by:

$$\sigma = \sqrt{\frac{1}{N}\sum_{j=1}^{N}\left(v_j - \bar{v}\right)^2}$$, where $\bar{v}$ is the mean defined by $\frac{1}{N}\sum_{j=1}^{N} v_j$.

This gives us the daily volatility of the returns, but for comparative purposes, and as an input to the Black-Scholes formula, the annualised volatility is needed. This is obtained by multiplying the daily volatility by the square root of the number of trading days in a year, $\sqrt{250}$, if daily returns are used.

The unweighted average of the volatility of each company was 38%. However, this is perhaps not the best estimate of the aggregate volatility of all the companies, due to the fact that it gives equal weight to tiny companies (which generally have very high volatility of returns) and to large companies. The volatilities must be weighted by their relative market capitalization.

The market capitalization of a company j (M_j) is the aggregate value of its stock. The total market capitalization is the sum of the market capitalizations of each company. The ratios of the market capitalization of each company to the total market capitalization, $\left(\frac{M_j}{\sum_{k=1}^{224} M_k}\right)$, can be used to weight the volatilities of each stock. Larger companies will have greater market capitalization than smaller companies, and so the volatility of the returns of the larger companies will be weighted more heavily in the overall volatility. The weighted average volatility of returns of the 224 telecom companies used by Indecon was 27%.

4.2.2 Estimates from Related Previous Studies

In our review of previous research, we collected and compiled various estimates of volatility that were used in other high-quality studies of real options in the telecommunications industry.

The table below presents Indecon's summary of the previous studies.

Table 4.4: Summary of Volatility Estimates

Authors	Commodity on which Volatility Estimate is based	Volatility Estimate
Harmatzis, Trigeorgis and Tanguturi (2006)	Share price of the company	38%
Harmatzis, Trigeorgis and Tanguturi (2006)	US Telecom Index for last 3 years	31%
Harmatzis, Trigeorgis and Tanguturi (2006)	Bombay Stock Exchange, Technology, Media and Telecom Index (BSE TECk)	47%
Harmatzis, Trigeorgis and Tanguturi (2006)	US Telecoms Index from 2002 to 2007	28%
Harmatzis, Trigeorgis and Tanguturi (2006)	Share price of the leading device manufacturer during the life of the project	85.6%
Harmatzis, Trigeorgis and Tanguturi (2006)	Share price of the hardware vendors	50%
Iatropoulos, Economides and Angelou (2004)	Interview data provided by company executives and experts in the broadband sector in Greece	20%, 40%, or 60%, depending on demand and costs
Verheijen (2007)	Telecoms Indices on the Euronext Amsterdam, NASDAQ, and NYSE stock markets	24.4% (Amsterdam), 23.9% (NYSE), 28.6% (NASDAQ)
Tanguturi and Harmantzis (2005)	Share price of the company	37.7%
Tanguturi and Harmantzis (2005)	US Telecom Index for the past three years	31.2%
Paxson and Pinto (2004)	Shares of the company from June 2000 to June 2003	43.5%
Paxson and Pinto (2004)	Quarterly data from 1998 to 2003 on the numbers of units sold by the company	14.4%
Paxson and Pinto (2004)	Share price of the equipment suppliers, Nokia and Ericsson, from June 2000 to June 2003	77.2%

Source: Indecon review of previous academic studies

Clearly, a wide range of volatilities have been used (20% - 85.6%). The highest volatilities were those for single companies, such as 38% (a wireless telephony company), 85.63% (a device manufacturer), and 43.5% (Optimus), or for a group of a small number of companies, such as 77.2% (for Nokia and Ericsson), and 50% (Lucent, Cisco and Nortel). The lower end of the range of volatilities is mainly composed of the indexes, such as the NYSE (24% from 2002 to 2007, 31% for a different three year period), the NASDAQ (28.56%), Amsterdam (24.35%). The main exception here is the Bombay telecom index, which had a relatively high volatility of 47%, but this is not relevant for the present application, due to the geographical remoteness of India from Ireland.

Since most of the OAOs are small to medium-sized companies with less than 100,000 customers, the volatility of their revenues is likely to be higher than that of the Telecom Indexes. Therefore, on the basis of previous research, an estimated volatility of 45% would be reasonable.

4.2.3 Implied Volatility

The implied volatility of an option is in effect solving backwards for the volatility of the option, for option contracts that have been traded on exchanges or over the counter (i.e., a traded price exists). The volatility of the underlying asset is the only parameter in the Black-Scholes formula which cannot be known with certainty before the expiry of the option, due to the fact that the volatility depends on the future realization of the asset returns. However, given the Black-Scholes option pricing model (and plugging in the other parameters), the current market price of the option (for traded contracts) implies a certain volatility of the underlying. This is also due to the fact that the option pricing model is monotonic in volatility, and thus, according to the inverse function theorem, there can be at most one value of the volatility that will cause the option pricing model's option price to equal a particular market option price. Finding the implied volatility amounts to solving the equation:

$U_o = u(S, X, r_f - g, T, \sigma)$ for σ, where U_o is the current market option price and u is the Black-Scholes option pricing function.

In general, there is no closed form solution to this equation for σ, and numerical methods, such as the Newton-Raphson method, the binomial method, or Brent's method, must be employed.

Using recent market prices for over six thousand option contracts, Indecon calculated the implied volatility of one hundred and five stocks for each trading day over a two month period, resulting in over quarter of a million implied volatility estimates. The average of these was 36.76%, but there was a large range. The table below shows the average volatility in each of the quintiles (each quintile contains approximately 1550 option contracts).

Table 4.5: Implied Volatility Quintiles

	Implied Volatility
First Quintile	25.5%
Second Quintile	30.4%
Third Quintile	36.5%
Fourth Quintile	54.6%
Total Average	36.7%

Source: Indecon analysis of telecom options data

4.3 Real Put Option Valuation Model

This subsection begins by introducing the Black-Scholes formula for valuing European style options and then moves onto explaining how the Black-Scholes formula is adjusted. This adjustment, the Barone-Adesi-Whaley method is used to value American style options, by adding an early-exercise premium to the European (Black-Scholes) option price.

4.3.1 Black-Scholes Formula for European Options

An analytical solution to the European put option pricing problem is given by the following Black-Scholes formula[16]:

$$p = Xe^{-(r_f - g)T} N(-d_2) - SN(-d_1) \text{, where}$$

[16] Black, F. and M. S. Scholes. 1973. The Pricing of Options and Corporate Liabilities. *Journal of Political* Economy 81:637-654

$$d_1 = \frac{\ln(S/X) + r_f T}{\sigma\sqrt{T}} + \frac{1}{2}\sigma\sqrt{T}$$
$$d_2 = d_1 - \sigma\sqrt{T}$$

And where

$X =$ strike price,

$S =$ price of the underlying asset,

$T =$ time to maturity,

$r_f - g =$ net discount rate,

$N(\ ) =$ standard normal cumulative distribution function, and

$\sigma =$ volatility of the underlying asset

The strike price is eircom's sunk bitstream costs per customer. The price of the underlying is, for the case currently being considered, the difference between the present value to an OAO of a bitstream customer and the present value of an LLU customer. While this is positive, the OAO will want to remain as a bitstream retailer. However, as the OAO continues to grow, it will eventually reach the scale where migrating its customers to LLU (intra-operator migration) is more profitable than remaining a bitstream retailer.

The time to maturity is the time that remains between the current date (the evaluation date) and the maturity date of the option.

The discount rate is the risk-free rate of interest.

4.3.2 The American Option Premium

The option held by the OAOs is not in fact a European, but rather an American, which means that it can be exercised at any time before or at expiry. The feature of American options causes their value to be different than their European counterparts. In order to value an American option accurately, one needs to adjust the Black-Scholes formula to include an early-exercise premium. There are a number of models for doing this, such as: the Adaptive Finite Element Method; the Binomial and the Trinomial Option Pricing Models; the Monte Carlo Method; the Finite-Difference Model; and the Barone-Adesi and Whaley Model. Our approach utilises the Barone-Adesi and Whaley model[17].

In the Barone-Adesi and Whaley approach, the American option price is equal to the European option price plus an early exercise premium.

$$P_t = p_t + A\left(\frac{S_t}{S^{**}}\right)^q \text{ if } S_t > S^{**}, \text{ and } P_t = X - S_t \text{ if } S_t \leq S^*.$$

P_t is the American put option price and p_t is the European put option price, determined by the Black-Scholes formula:

$$p = Xe^{-(r_f - g)T} N(-d_2) - SN(-d_1), \text{ where}$$

$$d_1 = \frac{\ln(S/X) + r_f T}{\sigma\sqrt{T}} + \frac{1}{2}\sigma\sqrt{T}$$

$$d_2 = d_1 - \sigma\sqrt{T}$$

In the Barone-Adesi and Whaley formula:

$$A = \frac{S^{**}\left|1 - e^{\sigma T} N(-d_1)\right|}{q_1}, \text{ where } q_1 = \frac{1 - n - \sqrt{(n-1)^2 + 4k}}{2} \text{ and}$$

$$n = \frac{2(r - \delta)}{\sigma^2} \text{ and } k = \frac{2r}{\sigma^2\left(1 - e^{rT}\right)}$$

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[17] Barone-Adesi, G. and R. E. Whaley. 1987. Efficient Analytic Approximation of American Options. *Journal of Finance* 42: 301-320

4.4 Evaluating the Intra-Migration Option Value

Indecon evaluated the option price in August 2008 of the option held by OAOs to migrate one of their bitstream customers to an LLU service. In general, the value of the option depends on the time at which the bitstream contract was initiated, our estimates of the net sunk costs per customer, akin to the strike price of the put, are based on the average depreciated value of assets as for the most recently available regulatory accounts. Thus they are an estimate of the average value for existing assets as of the most recent regulatory accounts.

Below we show the value of the option by various estimates of the volatility.

Table 4.6: Option Evaluation Results Sensitivity to Volatility

Volatility	Net Sunk Cost Per Customer	Value of Option As Of August 2008
27%	[redacted]	[redacted]
37%	[redacted]	[redacted]
45%	[redacted]	[redacted]

Source: Indecon

As signified above, this table shows the results of the option evaluation when the volatility is 27%, 37%, and 45%. The first value is based on Indecon's independent estimate based upon historical stock price data. It is a conservative estimate of volatility, because it is a weighted average of the volatilities of the returns of over 200 medium to large-size firms. It is likely that the volatility of the returns of most of the OAOs in Ireland is a good deal higher than this.

It is interesting to consider the sensitivity of the option evaluation model to higher and lower volatilities. Taking $\sigma = 37\%$, the option price is only slightly higher, and with $\sigma = 45\%$, the option value in each scenario is only slightly higher. While typically option values would be sensitive to the volatility, our option values are not. This is because we have estimated that the value of a bitstream customer is not much different from an LLU customer (the difference is close to zero). In this case, since the volatility represents a % change over a given time (a year) for an underlying value, then even a 45% change in a value that is very small (less than one) will be unlikely to rise above the strike price. The fact that there have been few migrations we believe is reflective of this fact.

4.5 Conclusion

In principle, eircom bitstream customers have been given an option to switch from bitstream to LLU, by 'putting' the value of bitstream-specific assets on to eircom. The value of this option is thus a real American put option.

The use of real options valuation techniques has been used widely to value flexibility. We have estimated this value based on these standard techniques.

The put option values are right about [redacted]. The main parameters are the strike price (X—the value of the sunk investment net of redeployment), the underlying value (S - the value of a bitstream customer relative to an LLU customer), the time to maturity, the risk free rate, and the volatility. While the option price might typically be sensitive to the parameter inputs, in our case, since the price of the underlying S is estimated to be close to zero, the values are not sensitive to the parameters other than the strike price (X) and the underlying price (S). The strike price is sensitive to the redeployment costs and the equipment costs.

The option price is increasing with the strike price. Since the strike price is a function of the depreciated equipment costs, the option value is sensitive to the estimate as well.

5 Annex: Review of Real Options Research in the Telecommunications Sector

This annex presents more detail on research into the use of the real options methodology in the telecoms sector. The cases cited give a range of estimates, and in some cases, the relevant parameters of the models, such as the volatility, give a broad indication of similar parameter estimates for our models.

The real options approach has been used to analyse cases involving telephony, broadband, Internet, cable, wireless etc. Alleman (1999, 2002a, 200b, 2003) uses the strategic benefits that options offer for issues such as cost modelling, modelling regulatory distortions, and strategic evaluation.[18] Economides (1999) applies real options in studying the economic principles on which cost calculations should be based.[19] Authors in Edelmann, Kylaheiko, Laaksonen and Sandstrom (2002) capture the strategic flexibility offered by real options in understanding the alternatives in the telecommunications industry.[20] Kutailakata and Lin find the investment threshold at which firms are indifferent to investing immediately and postponing the investment.[21] Basili and Fontini (2003) use the Black-Scholes formula to evaluate the aggregate option value of the UK 3G telecom licenses.[22] Herbst and Walz (2001) use the option of abandonment and the growth option to analyze the value of auctioned UMTS (Universal Mobile Telephone System) licenses in Germany.[23]

[18] Alleman, J. 2003. How should telecom companies be valued? *America's Network* 107: 34-40.

Alleman, J., and P. Rappoport. 2002. Modeling Regulatory Distortions with Real Options. *The Engineering Economist* 47: 390-417.

Alleman, J. and E. Noam. 1999. *Real Options: The New Investment Theory and its Implications for Telecommunications Economics.* Kluwer Academic Publishers.

Alleman, J. (2002). A new view of Telecommunications Economics, *Telecommunications Policy*, 26, 87-92.

[19] Economides, N. 1999. Real Options and the Cost of the Local Telecommunications Network in Alleman and Noam (2002) Op. cit.

[20] Edelmann, J., Kylaheiko, K., Laaksonen, P. and J. Sandstrom. 2002. Facing the Future: Competitive Situation in Telecommunications in Terms of Real Options. *Proceedings of the IAMOT2002 11th International Conference of Management of Technology.*

[21] Kulatilaka, N. and L. Lin. 2004. Strategic Investment in Technology Standards. *8th Annual real options Conference* Montreal, Canada.

[22] Basili , M. and F. Fontini. 2003. The Option Value of the UK 3G Telecom Licenses. *The Journal of Policy, Regulation and Strategy for Telecommunications* 5: 34 – 52.

[23] Herbst, P. and U. Walz. 2001. Real Options Valuation of Highly Uncertain Investments: Are UMTS-Licenses Worth Their Money. Working Paper, Department of Economics, University of Tuebingen, Mohlstr. Working paper available from http://www.wiwi.uni-frankfurt.de/Professoren/walz/umts.pdf

Furthermore, Paxson and Pinto (2004) show that a real options pricing model can offer a means of formulating the timing of the investment in 3G technology by Optimus, a Portuguese telecom operator.[24] D' Halluin, Forsyth & Vetzal, (2002, 2003) apply real options methodology to value wireless network capacity.[25] This involves evaluating American options or option with the possibility of early exercise.

5.1 Previous Relevant Research

The volatility of returns in the telecommunications industry is a critical factor in evaluating real option prices, so it is useful to summarize here the methods of estimating and the values of this parameter that have been found in some recent studies.

5.1.1 Flexible Investment Decisions in the Telecommunications Industry

Harmantzis, Trigeorgis and Tanguturi (2006) analyse five case applications of flexible investment decisions in the telecommunications industry using real options.[26]

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[24] Paxson, D., and H. Pinto. 2004. Third Generation Mobile Games – An Application of Real Competition Options. *Proceedings of the 8th Annual Real Options Conference*, Montreal, Canada.

[25] D'Halluin, Y., A. P. Forsyth, and R. K. Vetzal. 2002. Managing Capacity for Telecommunications Network Under Uncertainty. *IEEE/ACM Transactions on Networking* 10: 579 – 588.

D'Halluin, Y., A. P. Forsyth, and R. K. Vetzal. 2003. Wireless Network Capacity Investment. *Proceedings of the 7th Annual Real Options Conference*, Washington DC, USA.

[26] Harmantzis, F., L. Trigeorgis and V. Tanguturi. (2006). Flexible investment decisions in the telecommunications industry; case applications using real options. NET Institute Working Paper http://www.netinst.org/Harmantzis-Trigeorgis.pdf

The first case is the decision to invest in next-generation wireless networks, such as the UMTS (Universal Mobile Telephone System) and the CDMA (Code Division Multiple Access). The maturity of the deferral option (i.e., the time to expiry) is five years. The annualized standard deviation (i.e., the volatility) calculated from historical prices movements of the company, is estimated at 38%. The risk free rate, estimated from the yield of US Treasury bond rates in 2004 corresponding to the life of the project, is 3.64%. For the Discounted Cash Flow (DCF) valuation, cash flows are discounted using an average WACC (Weighted Average Cost of Capital) of 10%, a figure obtained from Katz *et al.* (2003)[27] for similar companies in the wireless telecommunications industry. Based on these parameters, the value of the option to delay developing the 3G network is estimated to be $27,000 based on the Black-Scholes formula. This is only about 0.01% of the investment cost in the 3G network for this provider (about $275m), or less than 0.1% of revenue per customer. Thus, the option to delay for this operator is quite small, because 3G as an option is "deep out of the money", i.e., it is unlikely to make money anytime in the near future, so the option to wait is not worth much.

The second case is the decision to invest in integrated wireless networks, such as WLANs (wireless local area networks) and the GPRS (general packet radio service). The life of the option to expand is three years, based on a common belief about the timing of 3G spectrum auctions in the United States. The Telecom Index (the IYZ) is used as a measure of volatility for the proposed integration model. The IYZ index has as a major component (70%) public companies that offer mobile telephony services. Annual volatility, calculated using historical price movements of the US Telecom Index for the past three years, is estimated at 31%. The risk-free rate is estimated at 2.62% based on the 2004 US Treasury bonds yields corresponding to the life of the option. The WACC is again taken to be 10.8%, the average WACC of similar companies in the wireless industry, of 10.8% (see Katz *et. al.*, 2003). Based on the Black-Scholes model, the option to expand by integrating GPRS and Wi-Fi is calculated to be $0.77 million. Again, this is a total value given investment cost of about $275m.

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[27] Katz, R. L. and Junqueira, C. 2003. Managerial Strategies and The Future of ROIC in Telecommunications. Working Paper, Columbia Institute for Tele-Information, Columbia Business School, Columbia University.

The third case is the decision to migrate to broadband wireless internet services (WIS). In a case study of BSNL, the Indian national telecom operator, the operator has the option to migrate from its current 2.5G system to next generation CDMA technology. Cash flows are discounted using a WACC of 15%, typical of Indian telecommunications companies. The life of the project T is five years. The annualized standard deviation calculated from the historical price movement of the Bombay Stock Exchange Technology, Media and Telecom Index (BSE TECk) is 47%. The risk free rate is 6.48%, estimated from yield of 5-year Government of India bonds. Based on the Black-Scholes model, the option value of migrating to cdma2000 (3G) is estimated to be $499 million. This is on the basis of a subscriber base of about 9m, or $4.6 average per customer/month or about ¼ of the value of the project investment costs.

The fourth case is the decision to deploy Wi-Fi networks in the enterprise market. The authors analyse a case study in which the company/client is located in downtown Manhattan and occupies five buildings with an average of 55 floors each. It needs to implement wireless services for its staff, synchronizing the company's office management software with personal wireless devices.

Given the expectations for the number of subscribers, carried voice, data traffic, and implementation costs for different approaches, two possible solutions are considered:

Mobile Solution: Wireless services are provided by a mobile operator. This requires the installation of a dedicated base station system and required infrastructure involving cabling, antenna systems, fiber-based repeaters, and the acquisition of the wireless handsets. The mobile operator will be responsible for providing voice and data services to the employees of the organization.

Hybrid Solution: Wireless services are provided by the company's IT department covering the company's facilities. The enterprise customer will install a WLAN system and implied infrastructure i.e., cabling, antenna systems, backhaul, etc., and the acquisition of the wireless handsets. VoWLAN and data services will be provided by the company's network within the company's facilities, and by a mobile operator outside the enterprise environment.

The volatility of the underlying asset for the mobile solution, which is determined from the historical price movements of the Dow Jones Telecom Index (IYZ)[28], is estimated at 28% annually. The annualized volatility for the hybrid solution, estimated from the historical price movement of the leading device manufacturer, is 85.63%. The risk-free interest rate of 4.25% corresponds to the current US Treasury bonds yields, matching the maturity of the option. For the Discounted Cash Flow (DCF) valuation, expected cash flows are discounted using a WACC of 10.8% (Katz *et. al.*, 2003). The life of the project, T, is five years.

From the Black-Scholes equation, the value of the option to expand when the mobile operator installs the base station and a DAS (distributed antenna system) is estimated at $4.45 million. The value of the option to expand when the operator does not install the base station and DAS systems is $2.67 million. This is in relation to a project investment cost of about $10m. The option to invest, when the company is willing to deploy its own Wi-Fi network to provide and serve its employees and pay the operator when out of premises, is estimated to be $90.5 million. The value of the option to invest in wireless services for 5,000 mobile subscribers, who are located on-campus, paying a monthly subscription fee for the services offered by the mobile operator who has installed one cell site and a DAS system in five on-campus buildings, is calculated to be $80.5 million.

[28] The time-period over which the volatility is estimated may cause the differences. Volatility may change over time, and the assumption of constant volatility over the life of the option is a maintained assumption of the Black-Scholes, and related, option models.

The fifth case is the decision to replace tradition PBX Systems with hosted VoIP services. The case study used is that of providing Hosted Voice over Internet Protocol (VoIP) Services for a small financial investment firm headquartered in downtown New York City. Projected savings are discounted at a discount rate of 10%. The firm desires to select the best solution based on comparative analysis of the Hosted solution with other systems currently available in the market. The problem is modelled as an American call option. The value of the underlying asset is the present value of savings when a Hosted solution is deployed instead of an alternative solution (IP PBX, TDM PBX, and Centrex). The investment cost includes the costs associated with service, phone, and staffing of the alternative solution. The life of the project is five years. Volatility, estimated from the historical stock price movement of hardware vendors (Lucent, Cisco, and Nortel) over the past five years, is 50%. The risk-free rate is 8%. The authors estimate the option value associated with choosing Hosted services instead of one of the alternative solutions (IP PBX, TDM PBX, and Centrex). The option value of Hosted VoIP solution with respect to Centrex is $2,333, with respect to IP PBX is $103,183, and with respect to TDM PBX is $142,322. These values represent between about 5% and 25% of the respective investment costs.

In the five cases reviewed by the authors, the option values ranged from quite small to significant. The relevance of this is that the value of an option cannot be assumed, guessed or easily intuited and that a formal modelling/estimation exercise must be undertaken.

5.1.2 Broadband Investment Analysis

Iatropoulos, Economides & Angelou (2004)[29] apply real options methodology to a real life investments scenario associated with a strategic decision by "Egnatia Odos S.A." (EO) to deploy an optical fiber backbone network along the "Egnatia Odos" national motorway. EO possesses an American deferral option on a dividend paying asset. The asset underlying this option is the potential stream of revenues from an investment opportunity that will materialize only once EO enters the broadband market any time starting in 2005, where the dividends are the revenues lost during the time EO deferred entry into this market. To analyse the investment decision of EO in 2005, Iatropoulos *et al.* used interview data provided by company executives and experts in the broadband sector in the country to arrive at specific assumptions concerning the parameters required by the Black-Scholes model. Interview questions were geared towards revealing the various estimates, assuming that actual entry would occur sometime between 2005 and 2008. As a result of these discussions and guided by related literature on broadband networks investment analysis, the authors considered three different values of volatility (20%, 40%, 60%) to express the range of potential revenues, which are strongly related to demand for broadband services, as well as the cost of investment on the high and the low level of their values.

5.1.3 Building a Citywide WiMax Network

Verheijen[30] (2007) examines the value of the option to deploy a citywide wireless WiMax network in the unlicensed band in Eindhoven. The volatility is estimated using daily closing prices stock data from the Euronext Amsterdam, NASDAQ and New York Stock Exchange (NYSE) stock markets. Since data for the Netherlands are only available for two years, while the time horizon of the project is five years, volatilities using two American telecommunications indices are calculated for verification purposes. All three volatilities calculated range between 23% and 29% and therefore 25% seems to be a reasonable estimate for the volatility in the Dutch telecommunications industry.

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[29] Iatropoulos, A. D., A. A. Economides and G. N. Angelou. 2004. Broadband Investments Analysis Using Real Options Methodology. Communications and Strategy 55: 45 – 76.

[30] Verheijen, M. F. 2007. From Experimentation to Citywide Rollout: Real Options for a Municipal WiMAX Network in the Netherlands. Masters Thesis. Eindhoven Institute of Technology. http://library.tue.nl/csp/dare/LinkToRepository.csp?recordnumber=632516

5.1.4 3G Wireless Broadband Migration

Tanguturi and Harmantzis (2005)[31] apply real options techniques to estimate the value of investment in two new ventures: (a) defer expansion from 2.5G to 3G networks and (b) expansion of a 2.5G network, using Wi-Fi as an alternative technology.

In case A, the maturity of the option is five years. The current price of the underlying is the present value of the future cash flows. The strike price is the present value of the investment cost, consisting of capital expenditures and operational expenditures. The annualized volatility, is calculated from the historical price movements of the company, and estimated at 37.68% annually. The risk free rate of 3.64% is consistent to the US Treasury Bond rates, corresponding to the life of project. For the DCF valuation, cash flows are discounted using the average WACC of the wireless industry, estimated to be 10.8% at the time of evaluation. The authors calculate the value of option to delay developing the 3G network to be $0.027 million. The authors also conduct sensitivity analysis in which the volatility is varied from 10% to 100% while the remaining parameters are unchanged.

In case B, the maturity of the option is three years. The annual volatility, calculated using historical price movements of the US Telecom Index for the past three years, is at 31.225%. The risk-free rate is 2.62% based on the 2004 US Treasury Bonds Rates corresponding to the life of the option.

[31] Tanguturi, V. P. and F. Harmantzis. 2005. Migration to 3G Wireless Broadband Internet and Real Options: The Case of an Operator in India. Working Paper, Stevens Institute of Technology, http://www.dbresearch.com/PROD/DBR_INTERNET_EN-PROD/PROD0000000000196813.pdf

5.1.5 Optimal Timing of 3G Investment

Paxson and Pinto (2004)[32] determine the optimal timing of 3G investment for one Portuguese mobile company, Optimus. They calculated three proxies for volatility: value, number of units and investment volatility. The proxy for value volatility was calculated as the standard deviation of the company shares. They used daily returns from June 2000 to June 2003 and obtained an annualised volatility of 43.5%. Using quarterly data from 1998 to 2003, they calculated a proxy for the volatility of the number of units. The annual volatility of the number of units is 14.4%. As a proxy for investment volatility they calculated the standard deviation of the returns of Ericsson and Nokia using daily returns from June 2000 to June 2003. The volatility of these companies was chosen as a proxy for investment volatility because these companies are suppliers of equipment, and, hence, their business is associated with the investment cost. The investment cost volatility is 77.2%. The risk free rate was assumed to be 5%.

[32] Paxson, D. and H. Pinto. Third Generation Mobile Games- An Application of Real Competition Options. *Working paper presented in the 8th Annual International Conferences on Real Options, Montreal , Canada*