Investment Decision in a Broadband Internet Network: A Real Options Approach

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Abstract: This article is a case study analysing the decision of a telecommunications operator to roll out ADSL infrastructures in areas of low population density. This type of investment is characterized by the risk of committing significant sunk costs for a low number of potential subscribers. In addition, the investment decision is complicated by the involvement of local authorities which are interested in offering broadband internet access to the local population, and are prepared to partially fund the project.
Real options are used to calculate the project's value and optimal timing of the investment. Particular attention is paid to provide detail on how to perform real options analysis and valuation. The option is evaluated with the binomial model and we explain how to estimate key parameters such as volatility.
The case study suggests that real options can produce a more sensible recommendation regarding investment timing than the net present value (NPV) rule. It also illustrates the benefits of real options beyond mere valuation aspects. In particular, this approach can help structure discussions with local authorities and enables the operator to establish a roll-out plan of ADSL infrastructures across the entire network.

Key words: Investment under Uncertainty; real options; telecommunications networks; case study.

In the past ten years, there has been a growing number of publications about the benefits of using real options, rather than the conventional net present value (NPV) rule, to support investment decisions in the presence of high uncertainty and flexibility.

The telecommunications sector is well fitted to the use of real options. Indeed, it combines high capital intensity with a high degree of uncertainty. In order to preserve competitiveness and enhance customer value, operators have to regularly upgrade their network with the latest technology. This involves the commitment of large sunk costs, whereas the profitability of

(*) The author is grateful for the comments of Bertrand Quélin (HEC) and of an anonymous reviewer. The author also would like to thank "the Operator" for accepting to test the real options model on actual investment decisions, and for funding her research.

the investment is faced with multiple uncertainties of a technical, commercial, regulatory, and competitive nature.

However, the literature on real options is concentrated on a few industries, like the oil industry, natural resources (mining, agriculture), electricity, and the pharmaceutical sector. In addition, the real options literature is dominated by theoretical contributions, with few detailed case studies. Most of the time, the real options theory is illustrated with simplified examples that do not reflect the complexity of a real investment decision. Case studies often lack details concerning the methodology used to calculate option value.

In this article, we present a case study, in which real options are used to make a decision on the optimal investment timing in the roll-out of an ADSL (Asymmetric Digital Subscriber Line) network in rural areas. The case describes a real investment decision.

Particular attention is paid to provide detail on how to perform real options analysis and valuation. We evaluate the option with the binomial model, and explain how to estimate key parameters such as volatility.

We explore the benefits of using real options to support an investment decision in a context of high uncertainty. As is traditionally done in the real options literature, we show that real options can lead to a more appropriate investment's valuation and optimal timing than the NPV approach.

In fact, the financial valuation of a project constitutes only one aspect of the investment decision process (ARNOLD & HATZOPOULOS, 2000). In this case study, we investigate other potential roles of the real options approach like communication with external parties involved in the investment, and the elaboration of a roll-out plan across the entire network.

The article is organized into three sections. The 1st Section describes the investment decision and explains how it can be analyzed through a real options approach. The 2nd Section concentrates on the option's valuation. The 3rd one is a discussion on the benefits of real options to the investment decision.

■ The investment decision

Context

The case study deals with the decision to roll-out an ADSL network by an incumbent operator ("the Operator").

The Operator has previously successfully launched ADSL services in the larger cities of the country. It is under the pressure of public authorities which want to promote equal access to broadband internet across the entire country. Therefore, the Operator is now contemplating the possibility of extending ADSL service to areas that are less densely populated.

IATROPOULOS *et al.* (2004) have studied a similar decision in which the company Egnata Odos S.A. was considering deploying an optical fibre backbone network along the most important Greek motorway. The authors point out that network investment decisions in low density populated areas present specific challenges. First, such investments carry the risk of committing significant sunk costs for a low number of potential subscribers. Secondly, the investment decision is complicated by the involvement of local authorities, which are interested in offering broadband internet access to the local population. The same characteristics apply to the investment decision considered by the Operator.

The economic potential of the project appears to be limited. As indicated above, the roll-out of ADSL necessitates the payment of costly infrastructures for a limited number of potential subscribers. In addition, the sociological profile of clients in the countryside is different from that of urban clients, and there is nothing to guarantee that they will be as interested in broadband internet as their urban counterparts. Lastly, the project's profitability could be significantly reduced by a decrease in selling prices. In urban areas, the Operator has experienced considerable pressure from new entrants, and the drop in selling prices, ordered by the regulatory authorities, has been greater than the Operator anticipated. Since prices are determined at a national level, the evolution of prices in rural areas remains uncertain, even if new entrants have made it clear that they will restrict their operations to urban areas.

On the other hand, local authorities are eager to maintain the attractiveness of their territory, both for their current resident population and for local companies. Therefore, they are interested in broadband internet access. In some areas where it is unprofitable for the Operator to invest in ADSL services on a standalone basis, local authorities are prepared to offer a "subsidy" to make up for the difference.

In this context, the Operator must determine whether it makes economic sense to deploy an ADSL network in areas with low population densities. The decision is taken in a decentralised manner, because the network will be rolled out progressively, on a case-by-case basis. More precisely, the decision is taken at Central Office ("CO") level. In this article, we present the decision to invest in ADSL in a CO for which the profitability of ADSL appears particularly uncertain.

Profitability and risk analysis of the investment decision

A business plan has been established over a 4-year time period. Table 1 summarizes the Net Present Value (NPV) of the project.

Table 1: NPV of the ADSL project in the studied Central Office (in Monetary Units - MU)

Project value (*S*)	36.6
Investment cost (*X*)	52.5
Project NPV	**-15.9**

With an expected NPV of -15.9 MU, the calculation shows that the ADSL technology is not profitable for this CO. However, since local authorities are eager to equip their territory with broadband internet access, the Operator considers negotiating a subsidy from local authorities which would amount to at least 15.9 MU.

The financial participation of local authorities does not remove a significant risk for the Operator.

The Operator performs a risk analysis based on Monte Carlo simulations on the project's NPV (Figure 1). Three main sources of uncertainty are taken into account: number of subscribers; prices when ADSL services are launched; and average decrease in selling prices in the two years following the launch (See Appendix A for the probability distribution of each of these sources of uncertainty, as well as the correlation rates between these variables).

Figure 1 - Distribution of the project's NPV (using Monte Carlo simulations) (with a subsidy of 15.9 MU)

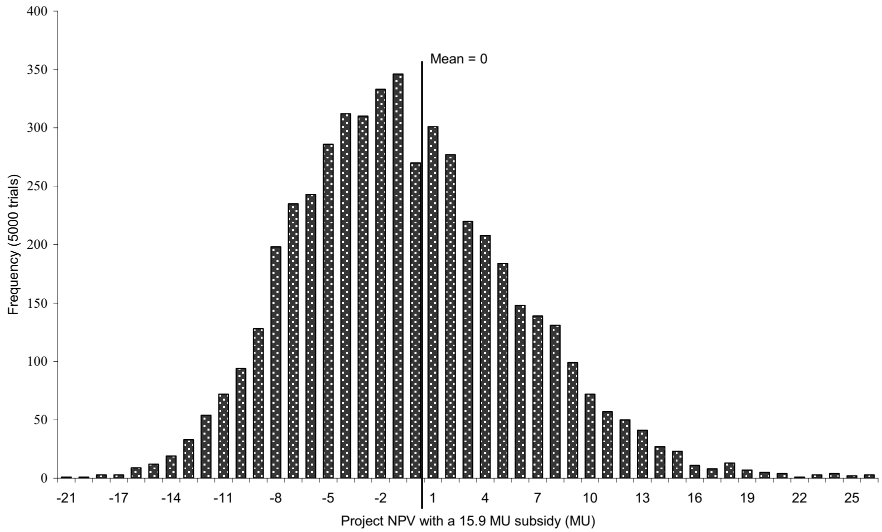


Figure 1 shows that the project is risky: whereas the investment cost amounts to 52.5 MU, the project NPV can be significantly negative, as much as -21 MU. Therefore, when the project is based on a subsidy calculated with a zero NPV, the Operator still faces an important risk with the deployment of ADSL infrastructures.

Given the high level of uncertainty, it is not clear from the Operator's point of view whether a 15.9 MU subsidy justifies an immediate roll-out of the ADSL technology.

Real option analysis of the investment decision

In contrast to NPV, real options explicitly take into account uncertainty, and enable managers to measure the value of waiting until uncertainty is reduced.

Real options analysis corresponds to the application of financial options theory to "real" investment decisions made by firms. The holder of a financial call option has the right, but is not obliged, to purchase a stock *S* ("the underlying asset") for a predetermined price *X* ("the exercise price") within a given period of time *T* (American option) or at a future date *T* (European option). If, during that period (or at the date *T* in the case of a European option), the stock price is higher than the exercise price, the option holder can exercise the option. This generates a pay-off which corresponds to the difference between the stock price and the exercise price. If the stock price remains lower than the exercise price, the option holder does not exercise the option, and the received pay-off is zero.

Similarly, an investment opportunity in a highly uncertain context can be analysed as an option. The stock price *S* corresponds to the cash-flows generated by the project. The exercise price *X* corresponds to the investment sunk costs which have to be incurred to launch the project. If the project is very risky, the company holding a real option can wait until the uncertainty on the value of the cash-flows generated by the project is (at least partially) resolved. Subsequently, if it turns out that the project value is higher than the investment sunk costs, the company can exercise the real option, i.e. make the investment. In the contrary case, the company abandons the option, i.e. does not invest.

In this case study, we can consider that the Operator holds an option to defer the ADSL investment. As indicated above, new entrants have announced that they would not provide ADSL services in suburban and rural areas until three years from now (at the earliest). Given the fact that it takes approximately one year between the date at which the investment decision is taken and the date at which the ADSL commercial service is launched, the Operator can postpone the investment decision by two years.

The option's value stems from the opportunity for the Operator to reduce uncertainty over the next two years. In order to determine future potential demand, the Operator can observe the success of ADSL in other central offices in rural areas, where ADSL has been launched on the basis of a more favourable business plan. There is also the opportunity to observe the acceptance rate for ADSL services in rural areas in other countries where this technology has been launched.

Regarding the evolution of selling prices, it can be expected that ADSL will become a more mature technology and that prices will progressively stabilize. In addition, the outcome of the price war will be much clearer; the pressure on prices should decrease over time, as the competitive structure becomes more clearly established. Generally speaking, the Operator will have much greater visibility regarding the evolution of selling prices in one year and *a fortiori* in two years.

The Operator can postpone the investment, and based on the information collected, invest in one year or in two years. If, in two years' time, economic conditions are still unfavourable, the Operator is not compelled to invest.

Technically, we can say that the Operator is holding an American option. Whereas European options can be exercised only when they expire, American options can be exercised at any date before the option expires. The option's lifetime is two years. After this period, other players may enter this market.

Waiting may be costly. In particular, the greater the length of time that the investment is postponed, the lower ADSL selling prices are likely to be. More significantly, the main negative impact of deferral on project value stems from the subsidy paid by local public administrations. The amount of the subsidy is at the sole discretion of local authorities. These bodies are interested in introducing cutting-edge technology to their areas which ordinarily would have been made available only years later on pure market criteria.

The longer time the investment is deferred, the less likely local authorities will be to participate financially. Their main financial interest is to retain or attract local businesses that need broadband internet access to stay competitive. Thus, the area can benefit from taxes paid by these small and medium-sized companies. The longer the ADSL roll-out takes, the more likely these companies are to move to other geographical areas with better infrastructures. In addition, it should be noted that other broadband internet access technologies, based on satellites, are tested. If ADSL deployment is postponed, local public administrations will be less willing to subsidize a technology that is likely to be replaced in the future by another technology.

Lastly, one must not forget that the political agenda of local authorities may change. In the future, they may decide to deploy amounts of money initially intended for the ADSL technology in other areas.

Overall, it can therefore be expected that the average project value will decrease if investment is postponed. From a technical point of view, this can be compared to a financial option on an underlying asset-paying dividend. The holder of such an option can keep the option alive as long as possible, with the hope that the stock price will increase, and the option pay-off will be greater. On the other hand, when the stock is paying a dividend, its value decreases by about the same amount. This entails a reduction in the option's value. The optimal exercise timing is then determined with the option valuation model.

Similarly in this case study, the investment deferral enables the Operator to collect information, but also entails a reduction in the project's expected value. The trade-off between the benefits (reduced uncertainty) and costs (reduced average project value) of waiting is not intuitive. It is necessary to estimate the option's value.

■ Real option valuation

We are dealing with an American option. The Black & Scholes model, which is the most commonly used model to evaluate options, is designed for European options. It is nevertheless possible to use Black's approximation to estimate the value of the American option, as is done is some case studies (BENAROCH & KAUFFMAN, 1999, 2000; IATROPOULOS *et al*., 2004).

In this article, we use the binomial model, which is more adapted to American options. We present the broad outlines of the model. More details concerning the binomial model can be found in real options manuals (e.g. AMRAM & KULATILAKA, 1999; COPELAND & ANTIKAROV, 2001). The calculations can also be performed by specialized software ("Real Options Analysis Toolkit", edited by Decisioneering Inc.).

Two steps are taken when performing the real option valuation with the binomial model: estimation of the input parameters, and calculation of the option's value.

Step 1: Calculating the value of the model's parameters

The working basis on which we conduct the analysis is the business plan which has been built by the Operator to calculate the NPV of the ADSL project at the Central Office level. The revenues and costs associated with the ADSL project are of course incremental i.e. they are the result of a difference between "with ADSL" and "without ADSL" scenarios, and, for example, take into consideration "cannibalisation effects" between ADSL services and traditional telephone services.

Exercise price (X)

The exercise price corresponds to the investment cost incurred in the deployment of ADSL infrastructures.

It turns out that part of the investment cost can be adjusted, depending on the number of potential clients. Such "variable" capital expenditures have to be reintegrated into the value of the underlying asset, since the binomial model is built on the assumption of a fixed exercise price. In addition, the investment cost is reduced over time, thanks to technical progress that can be expected on a technology like ADSL, which is not yet fully mature. We have assumed a technical progress rate of 5% per annum (p.a.).

Taking these elements into consideration, we come up with an exercise price X_1 of 49.4 MU if the option is exercised in one year, and a price X_2 of 48.9 MU if it is exercised in two years.

Value of the underlying asset (S) and of dividend (δ)

The value of the underlying asset corresponds to the present value of cash flows generated by the provision of ADSL services. In our case, the underlying asset is paying "dividends", i.e. its value is reduced when the investment is postponed.

On the revenue side, the number of potential subscribers is impacted positively by a project's deferral. We have assumed that if the launch of ADSL is postponed by two years, the sales volumes would take off more quickly than if this investment was undertaken immediately.

On the negative side, this phenomenon is counterbalanced by the fact that selling prices are decreasing sharply over time. Moreover, the expected subsidy given by local authorities is likely to decrease over time. We have assumed that in case of deferral, the probability distribution of the subsidy was the following:

- In 10% of the cases: the subsidy is zero;
- In 10% of the cases: the subsidy is the same as if ADSL investment was undertaken immediately;
- In 80% of the cases: the subsidy will be reduced by 10% if ADSL investment is postponed by one year, and reduced by 20% if ADSL investment is postponed by two years.

Taking these elements into consideration, we come up with an underlying asset value S_1 of 44.0 MU if the option is exercised in one year, and a value of S_2 of 40.2 MU if it is exercised in two years. The dividend δ corresponds to the difference between these two values and amounts to 3.8 UM.

Project volatility (σ)

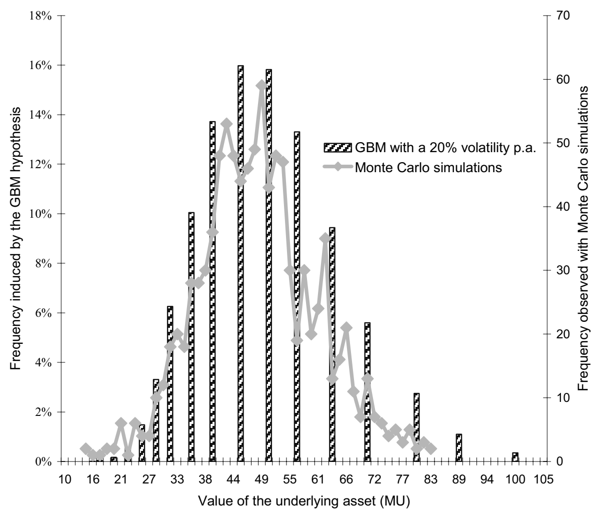
Project volatility is a key parameter in the option valuation model. We will see later that the level of volatility has a significant impact on the investment recommendations (see Figure 4). However, this parameter is difficult to estimate intuitively, as suggested by some researchers (BORISON, 2005). The difficulty stems from the fact that volatility results from the combination of several sources of uncertainty which are often correlated with each another. Each source of uncertainty can itself be subdivided into several variables.

For example, in order to model demand uncertainty, we have to specify the probability distribution of sales volume for each year, and across the whole range of product lines. In our case, there are five product lines, depending on the type of offering "package", the provider of the internet access (the Operator or an alternative operator) and the up and down traffic capacity. It is also necessary to indicate the correlation rate between individual variables. For example, we have assumed a negative correlation between selling prices and the customer base (see Appendix A).

Therefore, as suggested by COPELAND & ANTIKAROV (2001), the most appropriate method to estimate the volatility parameter is to conduct Monte Carlo simulations on the value of the cash flows generated by the project. In this case study, we follow this methodology, and use the data presented in the previous section for the NPV risk analysis.

The binomial model, like the Black & Scholes model, assumes that the underlying asset follows a Geometrical Brownian Movement (GBM), and that the distribution of the underlying asset value at the expiry of the option is log-normal. Figure 2 shows that a log-normal distribution obtained with a 20% annual volatility parameter σ constitutes a good approximation of the distribution revealed by Monte Carlo simulations.

Figure 2 - Estimation of the volatility parameter using Monte Carlo simulations



The other parameters of the binomial model are the option's time to expiry *T* and the risk-free rate *r*. As explained above, the lifetime of the option is of two years. The risk-free rate has been set at 4.5% p.a. Since we use a tree in which each year is divided into 6 periods, we have a discount rate per period *r* equal to 0.75 %.

Step 2: calculating the option value

Valuing the option with the binomial model follows a two-step approach. The details of the calculations are provided in Appendix B.

Firstly, we build a tree simulating the possible evolution of the underlying asset value. The starting point is S_2, the average expected present value of the project if the option is exercised at maturity. In our case, this value is currently estimated at 40.2 MU. At the subsequent time period, this value could rise and be multiplied by the *u* factor with a probability of *p*, or drop and be multiplied by the *d* factor with a probability of (*1-p*).

The *u*, *d* and *p* variables are calculated as follows:

$u = \exp(\sigma)$; $d = 1/u$; $p = \exp(r - d) / (u - d)$

Similarly, each of the two obtained values can thereafter be multiplied by *u* or *d*, and so forth. Therefore, we achieve a range of possible values of the underlying asset at the option's maturity. In this case, Appendix B shows that the underlying asset value in two years can range from 15.1 to 107.2 MU.

In the case of an option on an underlying asset paying a dividend, the tree has to be modified at the dates when the dividend is paid. For each point in the tree between now and the end of year 1 (periods 0 to 6 on Appendix B), we increase the project value by the dividend value δ, actualized at the date considered on the tree.

The second-step calculations indicate all the possible values of the option at the various points in time of the tree. This tree is built recursively, starting at the date of the option's maturity (period 12). At this date, we can figure out for each possible value of the underlying asset whether it is worth exercising the option, and calculate the resulting pay-off (which is equal to the difference between the underlying asset value and the exercise price X_2).

We then move back from period 12 to period 11. The value of the nodes in period 11 is deducted from the values in period 12, by using the *p* and (1-*p*) probabilities. Since we move back one period of time, this average is multiplied by an actualization factor of exp (-*r*) We proceed like this with all nodes of the tree. An exception is period 6, i.e. the end of year 1, where we have the possibility of exercising the option early. For all the nodes at this period, we calculate the maximum of the two alternatives: either the option is exercised, and the resulting pay-off equals the difference between the underlying asset value at this date and the exercise price X_1, or the option is best kept alive, and the option value is calculated as explained earlier as the actualized average value from the next period. Finally, by working the tree backwards, we obtain an option value of 2.90 MU.

■ Benefits of using real options in the investment decision

In this section, we explain the impact of real option valuation in the investment decision. We also believe that the benefits of the real options approach go beyond the mere project valuation. More specifically, this case study shows that real options can play a communication role, as well as a role of preparing future decisions (see Table 2).

Table 2 - Benefits of real options analysis to the investment decision

Stage of the decision	*Situation at the Operator*	*Benefits of real options*
Initial decision	Undervaluation of the project's NPV through a reduction of the project's lifetime	More appropriate recommendation than NPV on the minimum level of subsidy required, and on the optimal investment timing
	Difficulty for the Operator to demonstrate the risk of investing in ADSL infrastructures in low density populated areas	Establishment of a clear link between the level of uncertainty and project value Creation of a constructive basis to negotiate a subsidy with local authorities
If the decision is postponed	Bad visibility on the number of Central Offices, in which ADSL infrastructures will be deployed in the next two years	Possibility to estimate the probability that ADSL will be deployed in the next two years Creation of a roll-out plan across all central offices of the Operator's network

A more appropriate estimation of project value and optimal investment timing

The NPV and the real option calculations lead to different recommendations regarding the minimum subsidy level which has to be negotiated with local authorities for an immediate roll-out of the ADSL network.

As indicated in the first section of the article, the NPV calculation indicates that the ADSL network can be deployed immediately as soon as the subsidy is equal to (or greater than) 15.9 MU. The real options approach shows that such a calculation does not take into consideration the advantages gained by waiting.

Indeed, postponing the investment would enable the Operator to collect information on the profitability of an ADSL network. If the subsidy amounts to 15.9 MU, the NPV of the project undertaken immediately is 0, which is inferior to the deferral option value of 2.90 MU.

This shows that the "premium" which should be paid for an immediate deployment of the ADSL network is greater than 15.9 MU. The minimum level of subvention that should be negotiated can be determined graphically, as represented on Figure 3.

Figure 3 - Comparison of the level of subsidy recommended by the NPV calculation and by the real options approach

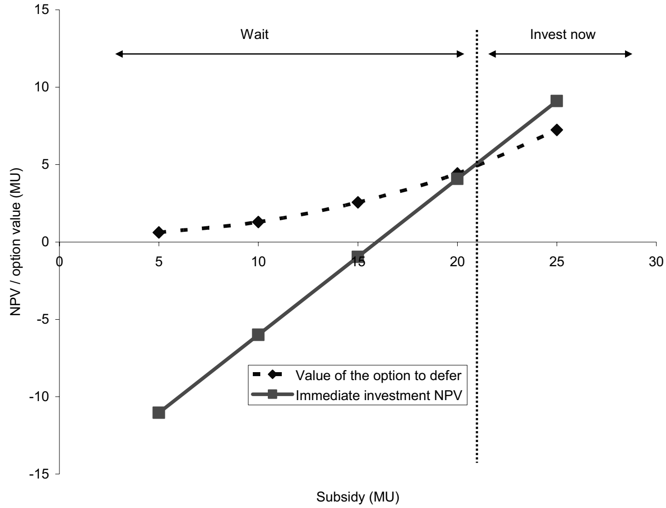


Figure 3 represents the project NPV if undertaken immediately, as well as the value of the option to defer, depending on the level of financial participation of the local authority.

If the Operator were following an NPV approach, then it would invest as soon as the "immediate investment NPV" becomes positive, which corresponds to a subsidy of 15.9 MU. By contrast, the real options approach recommends postponing the investment as long as the immediate investment NPV remains inferior to the deferral option value. On Figure 3, the "immediate investment NPV" line intersects the option value line only when the subsidy level amounts to 21 UM. Thus, the real options framework recommends a minimum subsidy level, which is about 30% higher than the subsidy recommended by the NPV rule.

Intuitively, this can be explained by the fact that the total value of the project corresponds to the sum of the "immediate investment NPV" on the one hand, and of an "opportunity cost" – which corresponds to the deferral option – on the other hand. If the option value is greater than the "immediate investment NPV", then the "expanded" NPV is negative and the project should not be undertaken immediately, even if the "immediate investment NPV" is positive. Conversely, if the option value is inferior to the "immediate investment NPV", then it is best to invest immediately.

Thus, real options analysis enables managers to understand why it is not necessarily best to invest immediately, even if the project's NPV is positive.

Academic literature indicates that this shortcoming of the NPV rule is often intuitively perceived by managers. In order to reduce the NPV, managers often use high actualization rates (BUSBY & PITTS, 1997). We observed a similar practice with the Operator. The actualization rate could not be modified because it was set for all the network investment projects of the company. Instead, we noticed that management undervalued the NPV by using a number of years of cash flows which was inferior to the actual economic project lifetime: NPV was calculated over a three-year period, whereas the infrastructure lifetime was approximately five years. The use of the real options approach would have enabled management to come up with an appropriate investment recommendation without having to "manipulate" the NPV calculation.

A communication tool establishing a clear link between project uncertainty and project value

Real options enable not only a better understanding of project value internally, but also better communication with external parties about the project value.

In some rural and suburban areas, local authorities suspected that the Operator was taking advantage of its position as the incumbent operator, and was trying to impose an inflated subsidy level. For the Operator, it was therefore important to offer greater visibility on the criteria leading to the decision of rolling out ADSL rapidly. In this regard, the real options approach presents two advantages over the NPV rule.

Firstly, real options help to model risk in a more concrete manner than the NPV rule does. With the NPV calculation, risk is taken into account through the choice of the actualization rate. This rate results from the combination of several factors, and few managers are in a position to justify the calculations performed to estimate its value[1]. Therefore, the calculation of the NPV – and hence of the minimum amount of subsidy – can appear quite arbitrary to external parties.

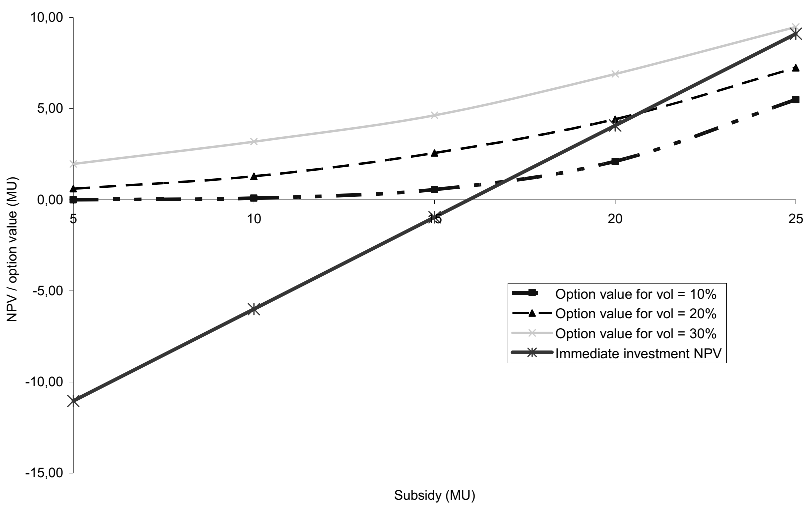
[1] The actualisation rate usually corresponds to the weighted average cost of capital (WACC). MCNULTY et al. (2002) show that the WACC can vary by substantial amounts depending on the initial hypotheses, in particular the period during which the market premium is calculated.

The benefit of real options is to translate the risk analysis from the denominator (the actualization rate) to the numerator (project cash-flows). This enables one to describe risk with variables which make sense economically, e.g. the minimal and maximal number of subscribers which can be expected in the next three years, and can be discussed with external parties.

Secondly, real options establish a clear link between the degree of uncertainty and the project's value. In the first section of this article, we performed Monte Carlo simulations on the project's NPV. Such an analysis reveals that the project is risky; however, it offers little guidance on the subsequent minimal amount of subsidy which should be negotiated with local public administrations.

In contrast, real options establishes a link between the degree of uncertainty and a project's value. Consistent with the real options theory, Figure 4 shows that the greater the volatility, the greater the option value. With growing volatility, the option's curve rises. Consequently, the subsidy required for an immediate investment in the ADSL network is greater.

Figure 4 - Impact of the volatility on the option value



Determining the option's value enables calculating how much it “costs” to take the risk of an early deployment. The parties can then arrange different contract structures, depending on who is bearing this risk. For example, if local authorities are eager to benefit from ADSL infrastructures as soon as possible, the Operator could make two different proposals supporting an early deployment of ADSL. This would be done either if local authorities accept to pay a subsidy of 21 MU, or if they accept the mechanism of a flexible subsidy. In this case, the subsidy would be adjusted ex-post, based on the value taken by predefined indicators (e.g. number of subscribers, retail prices). On average, the subsidy would be lower (ca. 15.9 MU), but local authorities would bear the risk of paying a higher subsidy in case of a limited success of ADSL in their area. Real options can thus help to ease negotiations between public authorities and an operator, when economic conditions are too limited to attract alternative operators and prices cannot be based on a competitive process.

A tool that facilitates the establishment of a roll-out plan across the whole network

So far, we have conducted an analysis for just one Central Office (CO). In fact, the Operator holds a portfolio of deferral options: there are approximately 100 COs in low density populated areas for which the decision to deploy ADSL is particularly uncertain. Deploying ADSL infrastructures mobilizes significant resources, and it is important to coordinate ADSL deployments across the entire country.

One of the benefits of the real options approach is that, in addition to a project's value, it calculates the probability of exercising the option. For example, for the studied CO, there is a 25% probability that the option is exercised at the end of year 2. Similarly, we can calculate the probability of anticipated exercise at the end of year 1. Thus, management can draw a consolidated picture of likely ADSL deployments across the country.

This type of analysis can be particularly useful, because it provides the Operator with a sense of the expected timing in the roll-out of ADSL technology across all Central Offices under study. Of course, this roll-out plan is valid only at a given point in time, and has to be updated when new information arrives.

Generally speaking, real options can be useful for all project decisions which are taken locally, but whose implementation requires the coordination of resources across the whole company. Here, we have taken the example of a network deployment, but this could apply as well to the roll-out of a new information system module across various entities of a company.

Conclusion and future research

This article illustrates the benefits of using real options to determine optimal investment timing in a telecommunications network with uncertain conditions and limited competition. When the pressure from competition is low, the operator has the opportunity to postpone the investment by several years, and thus holds an American option to defer.

Whereas the real options literature still relies significantly on theoretical contributions, this article offers insights in using an actual case study. The main contributions of this article are twofold.

For practitioners, this article provides a detailed application of real options analysis and valuation on real investment data. In particular, we present the binomial model which is well suited to the valuation of American type options. We also show how to calculate the value of parameters like dividend and volatility. Volatility is difficult to estimate; in many case studies, it is set arbitrarily, and then completed by a sensitivity analysis of volatility on the option's value. In this paper, we have used Monte Carlo simulations to estimate the level of volatility.

Secondly, this article explores the benefits of the real options approach for the investment decision. It shows that, in the context of uncertainty, real options can provide a more appropriate project valuation than the conventional NPV calculation. This stems from the fact that real options take into account the value of managerial flexibility: in this case, management has the possibility to defer the project, and to abandon it in two years time, should the economic situation become unfavourable. Because they incorporate the value of waiting into the analysis, real options can provide a more sensible recommendation on investment timing that the NPV approach.

This research also expands the traditional scope of analysis covered by the real options literature. Most articles concentrate on the role of real options as a pure valuation tool, which is used by one rational individual at a given point in time. This case study shows that real options can also serve as a communications tool when the investment decision involves external parties. This is particularly the case for network investment projects in rural areas in which there is a political will to encourage the deployment of infrastructures which would not be profitable on pure market criteria.

The case study also suggests that the benefits of real options do not limit themselves to the initial investment decision. If the initial decision is to postpone the investment, real options indicate the probability that the investment will be launched at a future point in time. This type of analysis can be particularly useful when the investment project involves a set of decisions which are taken locally for each site, but nevertheless require coordination across the company. Real options can thus help to establish a roll-out plan that will be regularly updated, and guide the organization along the entire project's lifetime.

This case study was conducted here as a pilot project of a real options application. Future research will need to test to what extent this approach can be effectively used by companies.

This raises two main questions. Firstly, is the framework simple and intuitive enough to be used by managers who are not familiar with the logic and tools of options? Secondly, to what extent does the organization exploit the flexibility described and valued by the real options analysis? In fact, one can observe some rigidities in the way organizations make decisions. Future research needs to work on the decision rights and compensation mechanisms which enable companies to capture the full value of real options.

Appendix A
Hypotheses used for Monte Carlo simulations

Monte Carlo simulations have been conducted by using the "Crystal Ball" software (edited by Decisioneering Inc.), which can be integrated into the Excel spreadsheet. Another well-known software for Monte Carlo simulations is "At Risk" (edited by Palisade).

Probability distribution of the main sources of uncertainty

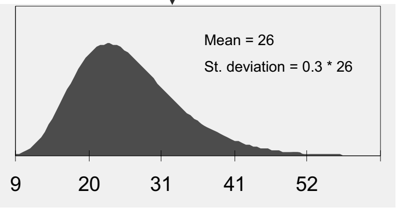
1) Number of subscribers

The business plan forecasts the number of subscribers for each of the 5 product lines, and for each year of exploitation. In total, we have therefore to model 15 variables. For each of these variables, we assumed a log-normal distribution with a 30% standard deviation. This distribution has the advantage of avoiding negative values, which makes sense for a number of subscribers.

SUBSCRIBERS BASE FORECASTS

	Year 1	Year 2	Year 3
Retail products			
# 1	6	10	15
# 2	1	2	4
# 3	15	26	48
# 4	1	2	4
Wholesale product	1	2	4

For each of the 15 variables, hypothesis of a log-normal distribution



For the other sources of uncertainty, we have assumed a triangular distribution:

2) Selling prices for year 1

Number of uncertain variables: 6 = 5 retail product lines + 1 wholesale product line
Probability distribution: Triangular
Parameters:
- Most likely value = selling price forecasted in the business plan
- Minimum value = 15% lower than the price forecasted in the business plan
- Maximum value = 15% higher than the price forecasted in the business plan

3) Average yearly price decrease during the year 1 to year 3 period

Number of uncertain variables: 6 = 5 retail product lines + 1 wholesale product line
Probability distribution: Triangular
Parameters:
- Most likely value = yearly price decrease forecasted in the business plan
- Minimum value = yearly price decrease 5% lower than forecasted in the business plan
- Maximum value = yearly price decrease 15% higher than forecasted in the business plan

Correlation coefficients between the sources of uncertainty

a) Correlation between the number of subscribers for different product lines in year 1: 80%

b) For a given product line, correlation between:
- the number of subscribers in year 1 and ADSL selling prices in year 1 : -50%
- the number of subscribers in year 2 and the yearly decrease in ADSL selling prices: 50%

c) Autocorrelation rate through time for the number of subscribers of a given product line: 80%. COPELAND & ANTIKAROV (2001) suggest an autocorrelation rate through time of 90%. We set it somewhat lower, to take also into consideration the fact that for a given sales volumes when the product is mature there are different possible market penetration speeds.

Appendix B

Calculation of the real option's value with the binomial model

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
2														
3	**Step 1a: Event tree of the underlying asset S_2 (after payment of the dividend δ)**													
4	**Year 0**	**Year 1**						**Year 2**						
5	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	
6	40.2	43.7	47.4	51.4	55.8	60.5	65.7	71.2	77.3	83.9	91.0	98.8	107.2	
7		37.1	40.2	43.7	47.4	51.4	55.8	60.5	65.7	71.2	77.3	83.9	91.0	
8			34.2	37.1	40.2	43.7	47.4	51.4	55.8	60.5	65.7	71.2	77.3	
9				31.5	34.2	37.1	40.2	43.7	47.4	51.4	55.8	60.5	65.7	
10					29.0	31.5	34.2	37.1	40.2	43.7	47.4	51.4	55.8	
11						26.7	29.0	31.5	34.2	37.1	40.2	43.7	47.4	
12							24.6	26.7	29.0	31.5	34.2	37.1	40.2	
13								22.7	24.6	26.7	29.0	31.5	34.2	
14									20.9	22.7	24.6	26.7	29.0	
15							= G11 * *d*			19.3	20.9	22.7	24.6	
16											17.8	19.3	20.9	
17												16.4	17.8	
18													15.1	
19														
20	**Step 1b: Event tree of the underlying asset S_1 (before payment of the dividend δ until period 6)**													
21	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	
22	44.0	47.5	51.2	55.3	59.7	64.4	69.6	71.2	77.3	83.9	91.0	98.8	107.2	
23		40.9	44.1	47.5	51.3	55.3	59.7	60.5	65.7	71.2	77.3	83.9	91.0	
24			38.0	40.9	44.1	47.6	51.3	51.4	55.8	60.5	65.7	71.2	77.3	
25				35.4	38.1	41.0	44.2	43.7	47.4	51.4	55.8	60.5	65.7	
26					32.9	35.4	38.1	37.1	40.2	43.7	47.4	51.4	55.8	
27						30.7	33.0	31.5	34.2	37.1	40.2	43.7	47.4	
28							28.6	26.7	29.0	31.5	34.2	37.1	40.2	
29								22.7	24.6	26.7	29.0	31.5	34.2	
30									20.9	22.7	24.6	26.7	29.0	
31										19.3	20.9	22.7	24.6	
32					= H12 + δ * $(1+r)^6$						17.8	19.3	20.9	
33												16.4	17.8	
34													15.1	
35										= max (N22 - X_2 ; 0)				
36	**Step 2: Option value tree**													
37	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Exercise?**
38	**2.90**	4.2	6.0	8.4	11.5	15.4	20.2	24.2	29.9	36.1	42.9	50.2	58.3	Yes
39		1.5	2.3	3.4	5.1	7.3	10.3	13.8	18.3	23.4	29.1	35.4	42.1	Yes
40			0.6	1.0	1.7	2.7	4.10	6.2	9.1	12.9	17.5	22.7	28.4	Yes
41				0.2	0.4	0.6	1.1	1.8	3.1	5.0	7.9	12.0	16.8	Yes
42					0.0	0.1	0.1	0.3	0.5	1.0	1.9	3.6	6.9	Yes
43						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	No
44							0.0	0.0	0.0	0.0	0.0	0.0	0.0	No
45								0.0	0.0	0.0	0.0	0.0	0.0	No
46									0.0	0.0	0.0	0.0	0.0	No
47										0.0	0.0	0.0	0.0	No
48	= max (H28 - X_1 ; (p * I44 + (1-p) * I45) * exp(-r))										0.0	0.0	0.0	No
49												0.0	0.0	No
50													0.0	No
51														
52		**Parameters**		S_2	40.2		σ	20%		u	1.085		= exp (I52 * sqroot (1/6))	
53				δ	3.8		r	0.75%		d	0.92			
54				X_1	49.4		X_2	48.9		p	0.53			

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