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The option to expand to a next generation access network infrastructure and the role of regulation in a discrete time setting: A real options approach

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ABSTRACT

Serious concerns have been raised, especially across Europe, about the role of regulation in network infrastructure investments. More specifically, the installation of optical fiber closer to customer premises, the so-called next generation access networks, requires massive investments in the face of demand and regulatory uncertainty. The purpose of this paper is to assess whether specific regulatory scenarios (permanent regulation, regulatory forbearance, regulatory holidays and sunset clauses) alter the timing of the investment decision of an incumbent to expand to a new network infrastructure exploiting the binomial lattice approach from real options analysis.

1. Introduction

For a National Regulatory Authority (NRA) promoting competition and, simultaneously, encouraging a telecom incumbent operator to invest in a new network infrastructure are two conflicting issues that are difficult to address underlying the trade-off between static and dynamic efficiency (Laffont & Tirole, 2000). Existing regulatory regimes, undoubtedly, promote effective competition but on the other hand can impede the deployment of next generation networks (NGNs) jeopardizing the potential emergence of new services. NGNs will enable unrivalled speeds and allow corresponding services to de-couple from underlying technology.

Similar to legacy network infrastructure, NGNs are divided in two parts: the NGN access part (NGANs) and the NGN core part of the network. The first part, basically, involves the introduction of optical fiber into the local loop at various levels and the second part refers to a backbone network (i.e. transport network) able to use IP technology. NGANs deployment encompasses three different levels relative to optical fiber deployment. The first level involves fiber being deployed between the main distribution frame (MDF) location and the street cabinet whilst retaining copper cabling from the street cabinet to customer premises (fiber-to-the-cabinet—FTTCab), the second level introduces fiber from the MDF location to the building (fiber-to-the building—FTTB) and the third level corresponds to a solution where fiber reaches the user's termination box (fiber-to-the-home—FTTH).

The differing views about the regulatory environment for NGANs deployment between incumbents and alternative operators – not to mention NRAs – actually reflect the current situation in the electronic communications market.

Incumbents claim that the existing form of regulation is not favorable to investments and it is actually delaying large scale network investments (i.e. NGN deployment) with the most characteristic example being that of Deutsche Telecom's

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plan for a very high DSL network (VDSL), back in 2005, asking from the NRA a non-regulation regime as a precondition for its roll-out. European authorities did not concede to this demand. The European Court of Justice ruled that the German telecoms law,[1] which provides an exemption from regulation for new markets actually breach the European Union (EU) law.[2] Despite the disapproval of a regulatory holiday in Germany, the EU recognizes the importance of NGN deployment as a key factor to economic growth across Member-States amid fears for a downturn in network investments due to the economic crisis. The European Commission (EC) adopted a new recommendation on regulated access to NGANs (European Commission, 2010) in order to promote NGN investments. Furthermore, the Body of European Regulators for Electronic Communications (BEREC) was established in order to enhance cooperation between NRAs that will, eventually, lead to a consistent approach regarding remedies on NGN (EU, 2009).[3]

On the other hand, alternative operators believe that ex-ante regulatory remedies imposition to incumbents has triggered competition where non-previously existed (legacy networks—xDSL) and that higher investments can only take place in better regulated markets (ECTA, 2010),[4] by-passing the fact that wholesale regulation promotes a free-riding behavior by relying heavily on the incumbents' infrastructure.

NRAs should be in a position to provide incentives to incumbents to develop their own NGN platforms instead of undermining this effort by imposing unnecessary remedies, whilst retaining – and why not enhancing – current competition levels on the new infrastructure. In order for this goal to be achieved a regulatory paradigm shift is needed towards a more dynamic approach able to facilitate investments and not just to promote effective competition in the short-term. A new tool appropriate for a dynamic assessment of NGN investments is needed. This tool is real options analysis (ROA).

More specifically, this paper aims to contribute to the debate for NGN investment and the role of regulation by focusing on the impact of different regulatory scenarios (regulatory forbearance, permanent regulation, regulatory holiday and sunset clauses) on the timing of the investment by exploiting the binomial lattice method (BLM) from ROA. Section 2 presents a short literature review about regulation and broadband investments along with the application of real options (ROs) to electronic communications industry. The BLM method used is outlined in Section 3, whilst Sections 4 and 5 discuss the results produced by applying the methodology to a business case of VDSL deployment. Finally, Section 6 provides ideas for future work and concludes the study.

2. Literature review

The problem in investment appraisal in the real world is that a model is needed able to integrate the uncertainty component and to capture the flexibility of active management in future activities, and the most appropriate tool is ROA (Dixit & Pindyck, 1994). Traditional investment evaluation method such as discounted cash flow (DCF) analysis using the net present value criterion (NPV) are in several occasions inadequate because they assume a static framework (a "now-or-never" investment decision-making process) and that the invested capital is totally reversible which is not always true. Note that ROA should be considered as a complement to DCF analysis and not as a substitute.

2.1. Financial and real options

An option gives its holder the right but not the obligation to buy (call option) or sell (put option) an underlying asset (e.g. a stock) for a certain price (strike price) on a certain future date. Options on real assets are real options. The mapping between real and financial options according to Luehrman (1998) is shown in Table 1.

The total strategic value of an investment opportunity incorporates both the NPV of the project and the flexibility of management in terms of making midcourse strategy corrections in order to adapt to changes in the business environment due to uncertainty. In other words, the total strategic value, or else the expanded NPV (NPV^{+}O) of an investment opportunity, is given by adding to its NPV the value of the option (flexibility parameter). This flexibility parameter (i.e. option value, w) actually reflects the value of different types of options that exist relative to the investment opportunity and belong to different categories presented in Table 2.

2.2. Real options applications in electronic communications sector

ROs application to the broader information-communication technology (ICT) sector provides a foundation for this study. More specifically, ROs application in information technology (IT) investments was examined by Panayi and Trigeorgis (1998) and Benaroch and Kauffman (1999). As far as ROs applications to telecommunications investment is concerned, Kalhagen and Elnegaard (2002) examine the case of an incumbent's investment decision to upgrade its services from ADSL to VDSL, whereas Harmantzis and Tanguturi (2007) apply RO techniques to evaluate investments in the

[1] §a TKG in force 24 February 2004.

[2] OJ C 113 of 01.05.2010, p. 3.

[3] Regulation 1211/2009, European Parliament and Council. Retrieved from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32009R1211:EN:NOT.

[4] Retrieved from http://www.ectaportal.com/en/PRESS/ECTA-Press-Releases/2010/New-Report-links-competition-economic-recovery/.

Table 1
Mapping financial options to real options.

Symbol	Financial options	Real (call) options
S	Current underlying asset value	The value of the investment opportunity (present time)
X	Exercise/strike price	Investment outlay (sunk costs)
T	Time to expiration date	How long the investment opportunity exists
σ	Volatility	Riskiness of the investment opportunity
r_f	Risk-free interest rate	Risk-free interest rate
b	Dividends	The cost of waiting in terms of revenues or profits foregone

Table 2
Real option taxonomy.

Category	Description
The option to defer	The investor waits to see if investment conditions develop favorably in the future
The option to alter the operating scale (expansion option, contraction option)	The operating scale can be altered in several ways. For example if market conditions develop favorably then the investor might decide to expand its operations, otherwise to contract part of its operations for some cost savings
The option to abandon	If market conditions decline then current operations should be abandoned
The option to switch	A change in market conditions (e.g. demand or prices) can trigger a change in the output or input mix
Compound option(s)	It is a special case of options where the value of one option depends upon the value of another option. For example, an early investment (e.g. in R&D) could be the foundations for future growth opportunities. There is also the case of multiple phases projects where the success of the latter phases (i.e. later options) depend upon the success of previous phases (i.e. previous options). This is the occasion of sequential and not simultaneous options

Table 3
Description of regulatory regimes.

Regulatory regimes/ scenarios	Description
Regulatory forbearance	It refers to the situation where ex-ante regulation, that is the imposition of regulatory remedies is absent on NGN infrastructures
Permanent regulation	Remedies once imposed are “always on”
Regulatory holiday	There is a pre-defined period of time during which there are no regulatory constrains present. In other words, the NRA defers for a certain period of time before imposing its regulatory remedies
Sunset clauses	There is a pre-defined period of time after which the incumbent is not subject to any regulatory constrains, e.g. it is not obliged to offer its NGN infrastructure to alternative operators. In other words, there is a pre-specified period of time that remedies are in place before being withdrawn

wireless industry. Remaining in the same setting Lim, Lee, and Oh (2008) use BLM for evaluating the optimal investment timing for the IMT-2000, a 3rd generation mobile communications service. A discrete time analysis is also used by Brando and Dyer (2005) who combine in their model, ROA with decision tree analysis (DTA). Mastroeni and Naldi (2010) use ROs to assess the transferability value of telecommunications licenses. In Greece, Iatropoulos, Economides, and Angelou (2004) use ROs to evaluate optical fiber investments along Egnatia Odos motorway. Angelou and Economides (2007) combine fuzzy logic with ROA under competition threat.

ROs can also be used to investigate regulatory issues. Alleman and Rappoport (2002) use them to examine the impact of regulatory constraints on cash flows and Pindyck (2007) on the other hand, claims that optimal access prices should incorporate the option to delay as compensation to the incumbent for the asymmetric risk it needs to bear. Ergas and Small (2000) attempt to establish a relationship between the option to delay, regulation and economic depreciation. Camacho and Menezes (2009) address social welfare by proving that an option to delay pricing rule (ODPR) generates higher welfare than efficient component pricing rule (ECPR). An interested proposal is made by Siciliani (2010). He proposes that ROA can be exploited so that NRAs can set a fair access price, whilst the market will price the risk in NGANs deployment.

None of the above studies deals with the impact of different regulatory policy regimes (see Table 3 for a short review) on the overall level of an investment opportunity, especially on an incumbent's investment decision-making process to build an NGAN. This issue, mentioned by Cambini and Jiang (2009) in their literature review, is the focal point of this study along with the timing of the investment neglecting though the impact upon social welfare. The business case is taken from Kalhagen and Elnegaard (2002).

In order to assess the impact of regulation on an incumbent's investment decision to expand its operations to VDSL services it is necessary to explicitly define not only the existing regulatory regimes but also the manner of regulatory intervention, that is the type of regulation as well. International literature's different approaches to the most prominent type of regulation in electronic communications, that is price regulation, are (i) rate of return regulation (RoR) where the main task of the NRA is to adjust the level of price with respect to incumbent's operational and financing costs (Averch & Johnson, 1962), (ii) benchmarking regulation where the incumbent's performance is compared to the performance of other incumbent operators (Shleifer, 1985) and (iii) price-cap regulation where a formula determines the maximum allowable price increase (Littlechild, 1983). A similar to that approach is revenue-cap regulation where the NRA tries to cap incumbent's revenues. The manner of regulatory intervention in the business case of this paper is addressed in Section 4.2.

3. The model: binomial lattice method

One of the most well-known ROs valuation approaches, apart from closed-form equations (Black–Scholes formula developed by Black and Scholes (1973)), is the method of binomial lattices through the use of risk-neutral probabilities or market replicating portfolios. In this paper a simple (recombining) lattice approach with risk-neutral probabilities able to reflect a risk-neutral world is used. The main idea behind the lattice approach, which was first introduced by Cox, Ross, and Rubinstein (1979), is that the underlying asset value, S, at a given period of time may increase by a multiplicative factor u (the "up factor"), or decrease by a factor of d (the "down factor") giving the payoffs S_0u and S_0d at the next time step (δt) (Fig. 1).

As far as the term "recombining" is concerned it actually refers to a situation at which the middle node of S_0u's lower bifurcation is the same as S_0d's upper bifurcation at the very next time step (Fig. 2).

Each node in subsequent time steps can either increase or decrease, resulting in an expanding lattice of the underlying asset. The "up" and "down" factor values are based upon the volatility and the length of the time step. The time step size is obtained by dividing the time to expiration, T, of the option by the (desired) number of periods (i.e. steps) used.

More specifically, the basic structure of the binomial model analysis comprises from the following input parameters: (i) the underlying asset value (S), (ii) the exercise price of the option (X), (iii) the riskiness of the project (σ), (iv) the risk-free rate (r_f) and (v) the dividends parameter (b), as a percentage of the underlying asset S. Their presence actually reduces the option value.

The "up factor" mentioned earlier is denoted as

$$u = e^{\sigma\sqrt{\delta t}} \tag{1}$$

reflecting the increase of the underlying asset, whereas the "down factor"

$$d = \frac{1}{u} \tag{2}$$

symbolizes the decrease of the underlying asset. In other words, the latter follows a multiplicative binomial process over successive periods. After the evolution lattice of the underlying asset has been calculated, the next step is to proceed with

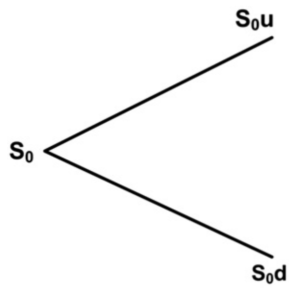

Fig. 1. The multiplicative binomial process.

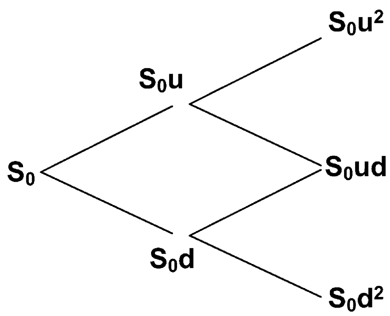

Fig. 2. A recombining lattice.

Table 4
Net present values for the three xDSL service forecast scenarios prepared by Kalhagen and Elnegaard (2002).

Scenarios	$NPV_{ADSL\ ONLY}$ (€)	NPV_{VDSL} (€)	Penetration (expiry date) (%)
Scenario 1	953 700	−50400	60
Scenario 2	986 200	111600	60
Scenario 3	1173 800	726100	65

the calculation of the option lattice using backward induction. The value placed in each terminal node is actually the maximum value between zero (or else stated) and the value that stems out from the execution of the option

$$V = \max(S-X, 0) \tag{3}$$

Intermediate nodes are calculated through the use of risk-neutral probability, that is

$$ROV = e^{-r_f \delta t}[pV^+ + (1-p)V^-] \tag{4}$$

delivering the value of the option if kept open with V^+ being the value of the option when the underlying asset's value has been increased and V^- the value of the option when the underlying asset's value has been decreased, following the aforementioned evolution. The risk-neutral probability is defined as

$$p = \frac{e^{(r_f - b)\delta t} - d}{u - d} \tag{5}$$

For the derivation of this equation see Mun (2006).

4. The option to expand to VDSL services: assumptions and option lattice calculations

In this section the BLM method is used to evaluate the total strategic value of an incumbent's investment opportunity to expand its operations to VDSL service provision taking into consideration four different regulatory scenarios (i.e. regulatory forbearance, permanent regulation, regulatory holiday and sunset clauses). Kalhagen and Elnegaard (2002) studied an incumbent's decision to invest or not in a VDSL upgrade in a suburban area. The area is considered to be covering 12 000 telephone subscribers with the subscriber density being equal to 1000 subscribers/km^2. In their nine-year case study period the incumbent offers ADSL services from the first year (year 0) and two years later (year 2) the incumbent decides whether to invest or not in a VDSL upgrade at a cost of 2 894 600€ (investment outlay) and provide VDSL services from year 3 and onwards. Incumbent's xDSL market share is considered to be 75%. Three different forecast scenarios of the total xDSL service take up are considered and according to traditional DCF analysis in all them the optimal decision for the incumbent is to stick to the ADSL path. In other words, the VDSL upgrade should be rejected as an option according to Table 4.

Performing ROA for the 3rd and most optimistic take-up scenario with saturation levels in terms of penetration reaching 65% at the end of the investment opportunity, using a volatility of 60% they get the total strategic value of the investment opportunity to be NPV$^+$O$=$2 119 400€. This analysis unveils that the VDSL upgrade should not be rejected as an option and due to large uncertainty it is possible to take place in year 2. A crucial issue that arises is whether a policy maker can exploit the binomial lattice approach described before not only to reconstruct ROA performed by Kalhagen and Elnegaard in a discrete time setting this time, but also to assess the impact of the timing of regulatory remedies imposition on an option to expand and see whether an earlier expansion can be achieved (American call option type). In this way a crystal clear picture of the impact of regulation on the overall investment opportunity can be obtained.

4.1. The evolution of the underlying asset

First, a discrete time model must be constructed in order to evaluate the option to expand to VDSL services and then assess the impact of regulatory remedies on its value. Input parameters for such a model include the underlying asset value, S, which is assumed to be the "ADSL only" NPV from scenario 3 (Table 4), that is S_0=1 173 800€, the strike price, already known, X=2 894 600€ at T=2 (i.e. time to expiration), a risk-free rate (r_f) of 5.5%, dividends yield,[5] b, and a high volatility value, σ=60%. The lattice of the underlying asset begins with S_0=1 173 800€ and projects potential future values following the "up" and "down" factors, u, and, d, that are calculated from the inputs of volatility, σ, and the time step size δt mentioned in the previous section. For performing lattice calculations eight steps (i.e. periods) are used resulting in a time step size that is equivalent to 0.25 years (quarter). As a result, the risk-free rate and the annualized volatility value must be adjusted to that particular time step size (periodic volatility, σ_p). Table 5 summarizes assumptions and parameter calculation used to evaluate not only the evolution lattice of the underlying asset (Table 6), but the option lattice as well for every regulatory scenario.

[5] Dividends yield in a real investment opportunity like this could imply that the incumbent looses market share in the xDSL market.

Table 5
Assumptions and parameter calculation.

Input parameters

$\sigma_\alpha = 60\% = \sigma_p\sqrt{4} \quad \therefore \sigma_p = 30\%$

$r_f = 1.38\%$

$T = 2$ years

$\delta t = \frac{T}{No\ of\ time\ periods} = 0.25$ years

Calculation parameters

$u = e^{\sigma\sqrt{\delta t}} = 1.16$

$d = \frac{1}{u} = 0.86$

$b = 0\%$ (no dividends)

$p = \frac{e^{(r_f - b)} - d}{u - d} = 0.47$

Table 6
The evolution of the underlying asset (unit 1000€).

T=0				**T=1**				**T=2**
Period 0 Now	**Period 1 0.25 years**	**Period 2 0.50 years**	**Period 3 0.75 years**	**Period 4 1 year**	**Period 5 1.25 years**	**Period 6 1.50 years**	**Period 7 1.75 years**	**Period 8 2 years**
								3897.15€
							3354.31€	S_0u^8
						2887.08€	S_0u^7	2887.08€
					2484.93€	S_0u^6	2484.93€	S_0u^7d
				2138.80€	S_0u^5	2138.80€	S_0u^6d	2138.80€
			1840.88€	S_0u^4	1840.88€	S_0u^5d	1840.88€	$S_0u^6d^2$
		1584.46€	S_0u^3	1584.46€	S_0u^4d	1584.46€	$S_0u^5d^2$	1584.46€
	1363.76€	S_0u^2	1363.76€	S_0u^3d	1363.76€	$S_0u^4d^2$	1363.76€	$S_0u^5d^3$
1173.80€	S_0u	1173.80€	S_0u^2d	1173.80€	$S_0u^3d^2$	1173.80€	$S_0u^4d^3$	1173.80€
S_0	1010.30€	S_0ud	1010.30€	$S_0u^2d^2$	1010.30€	$S_0u^3d^3$	1010.30€	$S_0u^4d^4$
	S_0d	869.57€	S_0ud^2	869.57€	$S_0u^2d^3$	869.57€	$S_0u^3d^4$	869.57€
		S_0d^2	748.45€	S_0ud^3	748.45€	$S_0u^2d^4$	748.45€	$S_0u^3d^5$
			S_0d^3	644.20€	S_0ud^4	644.20€	$S_0u^2d^5$	644.20€
				S_0d^4	554.46€	S_0ud^5	554.46€	$S_0u^2d^6$
					S_0d^5	477.23€	S_0ud^6	477.23€
						S_0d^6	410.76€	S_0ud^7
							S_0d^7	353.54€
								S_0d^8

Actually, Table 6 describes the base case on which to expand. Without an existing state present it is not possible to use an expansion option. Note, that a zero dividend yield[6] is assumed for the calculations performed. When exhibited they manifest themselves as a percentage of the underlying asset value (i.e. the NPV value of the "ADSL only" scenario). Their absence implies that there is no effect on the option to expand (option lattice calculations). In other words, in the aforementioned real investment opportunity, no dividends yield practically means that holding the option open for future expansion is costless for the incumbent.

The underlying asset value at the jth node ($j=0, \ldots, i$) at time $i\delta t$ ($i=0, \ldots, 8$) has the general form $S_0u^jd^{i-j}$. For example the value of the underlying asset at the bottom right terminal node ($i=8, j=0$) is 353 540€. At the terminal nodes the underlying asset can be anywhere between 353 540€ and 3 897 150€.

4.2. Option lattice calculations

Now, given the evolution of the underlying asset the option lattice is calculated. The cost of expanding to VDSL services is assumed to be $X=2\,894\,600$€ at any time over the next two years (option time to maturity). Next, the option evaluation and decision lattice is performed.

The terminal nodes of the option lattice will contain either the value from immediate expansion to VDSL or the value from continuing with current operations (ADSL service provision) depending upon which one of them constitutes an optimal investment decision. This can be expressed in a general form as

$$V_{j,8} = \max\{(Exp)S_0u^jd^{i-j} - RE(Exp)S_0u^jd^{i-j} - X, S_0u^jd^{i-j}\} \tag{6}$$

[6] See Table 5 and footnote 5 for their interpretation.

Table 7
The option valuation lattice under regulatory forbearance (unit 1000€).

T=0				**T=1**				**T=2**
Period 0 Now	**Period 1 0.25 years**	**Period 2 0.50 years**	**Period 3 0.75 years**	**Period 4 1 year**	**Period 5 1.25 years**	**Period 6 1.50 years**	**Period 7 1.75 years**	**Period 8 2 years**
				Unregulated phase				
								Node A
								12 596.58€
							10 448.72€	**Expand**
						8601.38€	Open	8581.55€
				Node B	7012.71€	Open	6992.95€	Expand
				5646.67€	Open	5626.97€	Open	5607.14€
			4484.42€	**Open**	4452.61€	Open	4432.85€	Expand
		3517.53€	Open	3466.40€	Open	3423.48€	Open	3403.65€
	2735.36€	Open	2669.24€	Open	2600.36€	Open	2536.28€	Expand
2119.54€	Open	2048.40€	Open	1968.35€	Open	1875.61€	Open	1771.26€
Open	1578.46€	Open	1502.33€	Open	1411.70€	Open	1292.52€	Expand
	Open	1165.30€	Open	1092.20€	Open	1002.89€	Open	869.57€
		Open	869.21€	Open	811.42€	Open	748.45€	Continue
			Open	673.94€	Open	644.20€	Open	644.20€
				Open	554.46€	Open	554.46€	Continue
					Open	477.23€	Open	477.23€
						Open	410.76€	Continue
							Open	353.54€
								Continue

where *Exp* stands for the expansion factor (i.e. expand from ADSL to VDSL services) and parameter *RE* denotes regulatory intervention in terms of regulatory erosion as a percentage of the expanded underlying asset. In other words, regulatory intervention does not allow the incumbent to fully reap out the benefits from its expansion to new (VDSL) services. It is assumed that this regulatory intervention translates itself in 25% erosion (i.e. reduction) of incumbent's profits from expanding to VDSL services when imposed.

The rest of the option lattice is computed via backward induction technique. In intermediate nodes the value placed is chosen between immediate expansion to VDSL services and keeping the option open for future expansion depending upon which one is greater. This is expressed as

$$V_{j,i} = \max\{(Exp)S_0u^jd^{i-j} - RE(Exp)S_0u^jd^{i-j} - X, e^{-r_f\delta t}[pV^+_{j+1,i+1} + (1-p)V^-_{j,i+1}]\} \quad (7)$$

Note that the value of keeping the option open and continue with existing service provision (i.e. ADSL) is the discounted weighted average of future option values using the risk-neutral probability, p (see Table 5 for its value).

In order to obtain an NPV$^+$O value of a similar magnitude with the one derived in Kalhagen and Elnegaard paper (i.e. 2 119 400€) under assumptions made, trials show that an expansion factor $Exp=3.975$ is needed. The result that is finally obtained from the binomial lattice approach following the aforementioned methodology (i.e. NPV$^+$O=2 119 540€) is slightly overestimated and it was preferred compared to an underestimated one that could have resulted via the use of a smaller expansion factor. An underestimated value could favor the incumbent in terms of eroding lower than real profits from expansion when regulatory intervention is actually imposed. Having used the full expansion factor in the aforementioned calculations illustrates that these calculations fall in the regulatory forbearance case. Table 7 presents the valuation and decision option lattice. Notice from the option lattice that at expiration date there are occasions (nodes) at which it is optimal for the incumbent to expand to VDSL services making really plausible to expand in year 2 ($T=2$).

For more analytic calculations relative to the evaluation of the above option lattice and more specifically nodes A and B see Appendix A. The same process also provides the calculation of the option lattices for the rest of the scenarios derived in a similar way (i.e. permanent regulation, regulatory holiday and sunset clauses). What really changes is the expansion factor in each regulatory scenario during the lifetime of the option. More specifically, in a continuous regulatory intervention the expansion factor will be truncated throughout the lifetime of the option, whereas in regulatory holiday and sunset clause case regulatory intervention is imposed and withdrawn, respectively, just after year 1 and onwards, thus creating two different phases (regulated and unregulated) during the lifetime of the option. Table 8 summarizes the results of the option lattices. Each row of the table illustrates the decision-making policy of the incumbent in terms of expanding or not as resulted from the calculation of the option lattices for each scenario.

Regulatory forbearance and sunset clauses scenarios give identical option lattices and the same total strategic project value (see Tables 7 and 8). The reason is that under the sunset clauses scenario calculations performed during the unregulated phase dominate over the calculations performed during the regulated phase (truncated expansion factor). In permanent regulation the total strategic value of the project is decreased due to the truncated expansion factor throughout the lifetime of the option. Finally, regulatory holiday is the only scenario that induces expansion long before

Table 8
Summary of the results (unit 1000€).

Regulatory scenarios	**NPV^{+}O**	***T*=0**				***T*=1**				***T*=2**
		Period 0 Now	**Period 1 0.25 years**	**Period 2 0.5 years**	**Period 3 0.75 years**	**Period 4 1 year**	**Period 5 1.25 years**	**Period 6 1.50 years**	**Period 7 1.75 years**	**Period 8 2 years**
		Unregulated phase								
Regulatory forbearance	2119.54€	O	O	O	O	O	O	O	O	E(5/9)
		Regulated phase								
Permanent regulation	1409.16€	O	O	O	O	O	O	O	O	E(4/9)
		Unregulated phase					**Regulated phase**			
Regulatory holiday	1971.67€	O	O	O	O	*E*(3/5)	O	O	O	E(4/9)
		Regulated phase					**Unregulated phase**			
Sunset clauses	2119.54€	O	O	O	O	O	O	O	O	E(5/9)
NPV^{+}O		The total strategic value of the project								
O		Keep the option open (all nodes)								
E(a/b)	(a) Number of nodes that is optimal to expand (upper half of the option lattice) (b) Total number of nodes	For the remaining number of nodes it is either optimal to keep the option open (intermediate nodes) or continue with existing operations (terminal nodes)								

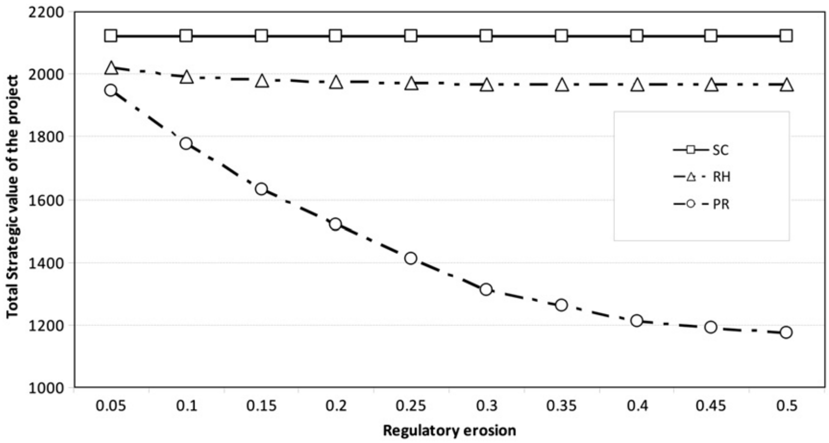

Fig. 3. NPV^{+}O (unit 1000€) and the regulatory erosion factor.

expiration date. More specifically, the incumbent is induced to expand to VDSL services when the "regulatory holiday season" ends as a result of the combination of a full expansion factor (unregulated phase that comes first) and a truncated one (regulated phase that follows).

Fig. 3 illustrates graphically the aforementioned trends of NPV^{+}O for each regulatory scenario (regulatory holiday—RH, sunset clauses—SC, permanent regulation—PR) as the regulatory erosion factor increases (it is assumed that this factor cannot exceed 50% of incumbent's profits from expanding to VDSL services).

What is interesting is the fact that the total strategic value of the project in regulatory holiday scenario is decreased as regulatory erosion factor increases but that is true up to the value of 30%. Beyond this value regulatory erosion factor has no impact on NPV^{+}O value. In other words, the unregulated phase remains "immune" to the regulated phase above this particular value.

4.3. The role of dividends yield

Aforementioned results are related to the absence of dividends. When a continuous stream of dividends is present throughout the lifetime of the option calculations (performed in the same manner as described above) change the results

Table 9
Summary of the results with dividend yield (unit 1000€).

Regulatory Scenarios	NPV$^+$O	*T*=0				*T*=1				*T*=2
		Period 0 Now	**Period 1 0.25 years**	**Period 2 0.5 years**	**Period 3 0.75 years**	**Period 4 1 year**	**Period 5 1.25 years**	**Period 6 1.50 years**	**Period 7 1.75 years**	**Period 8 2 years**
		Unregulated phase								
Regulatory forbearance	1805.08€	O	*E*(1/2)	*E*(1/3)	*E*(2/4)	*E*(2/5)	*E*(3/6)	*E*(4/7)	*E*(4/8)	*E*(5/9)
		Regulated phase								
Permanent regulation	1161.01€	O	O	O	*E*(1/4)	*E*(1/5)	*E*(2/6)	*E*(2/7)	*E*(3/8)	*E*(4/9)
		Unregulated phase					**Regulated phase**			
Regulatory holiday	1771.26€	*E*(1/1)	*E*(1/2)	*E*(2/3)	*E*(2/4)	*E*(3/5)	*E*(2/6)	*E*(2/7)	*E*(3/8)	*E*(4/9)
		Regulated phase					**Unregulated phase**			
Sunset clauses	1701.47€	O	O	O	O	O	*E*(3/6)	*E*(4/7)	*E*(4/8)	*E*(5/9)
NPV$^+$O		The total strategic value of the project								
O		Keep the option open (all nodes)								
E(a/b)	(a) Number of nodes that is optimal to expand (upper half of the option lattice) (b) Total number of nodes	For the remaining number of nodes it is either optimal to keep the option open (intermediate nodes) or continue with existing operations (terminal nodes)								

remarkably. Analogous to a stock, the total strategic value of the project reduces significantly. Actually their presence in a real life telecom project can be interpreted by the imposition on behalf of the NRA of more strict rules in the xDSL market segment (i.e. stringent unbundling obligations) in order to facilitate fiercer competition in that segment which in turn could result in a loss of market share for the incumbent and it implies that it is costly for the incumbent operator to keep the option open now and exercise it sometime in the future. In other words, when the cost of waiting to expand is high then the ability to defer reduces. This is true for the base case (i.e. the regulatory erosion set at 25% of incumbent's profits from expanding to VDSL services) when the dividend rate is set to 7.5% (as a proportion of the asset value), where it is no longer optimal for the incumbent to wait for the regulatory holiday season to end in order to expand to VDSL services but it is optimal to stop wasting time and expand immediately (Period 0). For the same dividend rate it is optimal for the incumbent to expand during Period 1 (0.25 years) under regulatory forbearance case, during Period 5 (1.25 years) under sunset clause scenario and during Period 3 (0.75 years) under permanent regulation scenario (Table 9).

Although, a particular dividend value can on its own induce the incumbent for an immediate expansion to VDSL services for any real life case outweighing all regulatory scenarios, it is extremely difficult such conditions to be triggered and appraised as a proportion of the asset value.

As a result, despite the fact that as a parameter, dividends, are not directly controllable by the NRA, intensifying access obligations in the xDSL market segment in favor of alternative operators and simultaneously providing a regulatory holiday for the new infrastructure to explicitly shape the conditions for an earlier expansion relative to the expiration date of the option can produce the desired outcome, that is the incumbent expands to VDSL services immediately.

It is now interesting to see whether regulatory holiday is a useful tool when the incumbent is subject to such kind of pressure in the xDSL market segment and when it is not (as a percentage of the underlying asset—i.e. dividend rate), and also when similar pressure exists in next generation infrastructure environment via the presence of competitive providers (CPs) that can truncate the full expansion factor during the unregulated phase and truncate even further the already truncated expansion factor due to regulation during the regulated phase.

5. Regulatory holiday: regulatory erosion factor and the role of competitors

If CPs enter next generation network market they will indirectly impose further profit reduction during the regulated phase whereas during the unregulated phase the incumbent will not fully reap out the benefits from expansion due to the truncated expansion factor.

The general form of the equations providing the option values in terminal and intermediate nodes of the option lattice is as follows:

$$V_{j,8} = \max\{(Exp)S_0u^jd^{i-j} - RE(Exp)S_0u^jd^{i-j} - CE(Exp)S_0u^jd^{i-j} - X, S_0u^id^{i-j}\} \quad (8)$$

Table 10
Results for several combinations of regulatory erosion, competitive erosion parameters, and dividend rate values (unit 1000€).

NPV^+O	T=0				T=1				T=2
	Period 0 Now Unregulated phase	Period 1 0.25 years	Period 2 0.5 years	Period 3 0.75 years	Period 4 1 year	Period 5 1.25 years Regulated phase	Period 6 1.50 years	Period 7 1.75 years	Period 8 2 years
Regulatory holiday (CE=10%, RE=10%, *b*=0%)									
1652.49€	O	O	O	O	*E*(2/5)	O	O	O	*E*(4/9)
Regulatory holiday (CE=40%, RE=40%, *b*=0%)									
1177.17€	O	O	O	O	*E*(1//5)	O	O	O	Continue
Regulatory holiday (CE=40%, RE=10%, *b*=40%)									
528.87€	O	O	O	*E*(1/4)	*E*(1/5)	*E*(1/6)	*E*(1/7)	*E*(1/8)	*E*(1/9)
Regulatory holiday (CE=40%, RE=40%, *b*=40%)									
528.87€	O	O	O	*E*(1/4)	*E*(1/5)	O	O	O	Continue
Regulatory holiday (CE=10%, RE=10%, *b*=10%)									
1391.42€	O	*E*(1/2)	*E*(1/3)	*E*(2/4)	*E*(3/5)	*E*(2/6)	*E*(3/7)	*E*(3/8)	*E*(4/9)
Regulatory holiday (CE=10%, RE=40%, *b*=10%)									
1388.03€	O	*E*(1/2)	*E*(1/3)	*E*(2/4)	*E*(3/5)	O	O	*E*(1/8)	*E*(1/9)

$$V_{j,i} = \max\{(Exp)S_0u^jd^{i-j} - RE(Exp)S_0u^jd^{i-j} - CE(Exp)S_0u^jd^{i-j} - X, e^{-r_f\delta t}[pV^+_{j+1,i+1} + (1-p)V^-_{j,i+1}]\} \quad (9)$$

where parameter *CE* indicates the competitive erosion as a percentage of the expanded underlying asset throughout the lifetime of the option. Similar to regulatory erosion factor it is assumed for the calculations performed that this factor cannot exceed 50% of incumbent's profits from expanding to VDSL services.

Absent dividends yield results show that as regulatory erosion and competitive erosion factor increase the trend is that the total strategic value of the project decreases. Furthermore, the same trend is observed as far as the number of nodes that is optimal for the incumbent to expand at the end of the holiday season and at terminal nodes as well. The reason for this is that the presence of CPs truncate the expansion factor during the unregulated period so that immediate expansion to VDSL services at the end of the regulatory holiday phase cannot overcome at all occasions the value of the option if kept open (computed via backward induction) despite the fact that the expansion factor during the regulated phase is suppressed even further due to the presence of CPs. The combination of high values for competitive erosion factor and low/high values for regulatory erosion factor needs unrealistic high dividend rate to induce the incumbent to expand towards present date, provided favorable returns (i.e. upper half node of the option lattice—Table 10). As long as the competitive erosion factor remains low, irrespective of the regulatory erosion level, a realistic dividend rate is needed for a similar outcome. This is because results during regulated phase depend upon both regulatory and competitive erosion levels, whereas unregulated phase results depend upon competitive erosion factor only. Dividends exhibition affects calculations throughout the lifetime of the option that is during both regulated and unregulated periods. Several combinations are shown in Table 10.

6. Conclusions and future work

The aim of this paper is to reveal how the financial metrics of an incumbent's investment opportunity are altered due to remedies imposition at some point during the time window that this investment opportunity exists, exploiting the BLM method from ROA. This method helps to explain what goes on behind the scenes when calculating a real options model in terms of providing a snapshot of the overall business opportunity (i.e. option lattice) along with the optimal decision for each node. As a tool it can be easily implemented by an NRA to address how critical factors (regulatory/competitive erosion as a percentage of the underlying asset, and the cost of holding the option to expand open for future execution—dividend rate) affect (i) optimal decision making at nodes (i.e. expansion before expiry date) and (ii) the overall strategic value of the overall business opportunity.

More specifically, results show that regulatory holiday triggers incumbent to expand to VDSL services at the end of the holiday season. Remedies imposition after the holiday season not only explicitly shapes the conditions for optimal execution of the expansion option before its expiration date, but also these conditions are actually enhanced by dividends yield (i.e. when holding the option open for future execution is costly). In fact, optimal execution of the incumbent's option long before expiration date can take place provided some fine-tuning among the intensity of the regulatory erosion factor during the regulated phase, the fact that the incumbent is subject to competitive erosion by CPs of its expansion profits during both the regulated and unregulated period and, finally, the cost of holding the option open for future execution. Therefore NRAs should examine more carefully the role of a regulatory holiday for NGANs in relation to competition levels in the xDSL market segment if their goal is to induce the incumbent to invest immediately. The provision of an unregulated phase could be considered as the means to compensate the incumbent for the triggering of fiercer competition in the xDSL market segment (i.e. more stringent regulatory intervention—e.g. unbundling rates) that could mitigate its incentive to postpone NGN investment for the future and not as a discrete policy alternative due to unaddressed market re-monopolization issues. In other words, inducing incumbent operators to invest in optical fiber networks before the option expires is about designing integrative policy models that would not only explicitly shape the appropriate conditions for the investment to take place but also to take into consideration the status quo of the industry (competitive erosion of the profits due to expansion, impact on the underlying asset when holding the option open is costly for the incumbent). Consistent approaches via tuning different aspects of the dynamic ICT ecosystem (as Bauer (2010) describes it) could, actually, pave the way forward.

Work needs to be done in cases where a telecom infrastructure investment project has multiple phases and latter phases depend upon the success of the previous phases (e.g. an incumbent decides to invest first in FTTCab and then in FTTH infrastructure) and a sequential compound option calculation is needed taking into consideration regulatory intervention. BLM method can be used to address the impact of regulatory scenarios described above for the assessment of such compound options via ''changing strikes'' (i.e. different investment outlays for each phase) and illustrate the effect on the overall investment.

Appendix A

In the text, having defined input parameters and the evolution of the underlying asset calculation process is as follows: Terminal nodes contain either the value of expanding to VDSL services or the value of continuing with the provision of ADSL services depending upon which one is the maximum (optimal investment decision). For example at node A (see Table 7 in Section 4.2) immediate expansion delivers

$$V_{8,8} = (Exp)S_0u^8 - X = 12\,596\,580€$$

which is greater than continuing current service provision ($S_0u^8 = 3\,897\,150€$). As a result the optimal decision at node A is to expand. The rest of the lattice is computed using backward induction which involves the risk-neutral probability, p, the risk-free rate, r_f, and the time step size δt for the calculation of intermediate nodes. For example, at node B immediate expansion delivers

$$V_{4,4} = (Exp)S_0u^4 - X = 5\,607\,140€$$

whereas keeping the option open is given by

$$ROV_{4,4} = e^{-r_f\delta t}[pV^+_{5,5} + (1-p)V^-_{4,5}] \tag{A.1}$$

The risk-neutral probability is then computed by

$$p = \frac{e^{(r_f-b)\delta t} - d}{u-d} = 0.47 \tag{A.2}$$

In turn, by substituting the value of the risk-neutral probability in Eq. (A.1) along with the relative option values the value of the option if kept open is $ROV = 5\,646\,670€$. Therefore, the optimal decision at node B is to keep the option open for future expansion. Continuing the same backward induction technique the starting point is reached with a value of 2 119 540€ which is the total strategic value of the investment opportunity (NPV$^+$O) and a pretty good approximation of Kalhagen and Elnegaard result (Table 7). Similarly, by taking into consideration the regulatory erosion factor in the aforementioned equations the rest of the option lattices are calculated.

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