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Investment flexibility and competition modeling for broadband business

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ABSTRACT

In the new era of the telecommunications business field, a large number of potential investors are capable of entering into the market of the broadband services provision. This paper provides a model for analyzing the new perspectives for new investors in this field. It integrates compound Real Options and Game Theory techniques and adopts price competition analysis, for the broadband services provision, in order to find the optimal business strategy. Finally, it applies the analysis to a real life business case by formulating and solving it.

1. Introduction

In the new era of the deregulated telecommunications business with a large number of potential investors, the Information and Communication Technologies (ICT) service providers seek access network solutions with even more bandwidth. However, communication solutions like Asymmetric Digital Subscriber Loop (ADSL) or WiMAX in fixed wireless communications experience recognizable limits of their capabilities mainly because of limited bandwidth. So far, the most viable solution for high bandwidth provision, especially in access networks, is the optical fibers technology. Hence, the installation of the optical fibers and their commercial exploitation is a very challenging business activity.

The main challenge for a potential provider (investor) is to roll out its business activity at the right time, the right scale and the right characteristics taking into account the threat from competition that the potential competitor can eliminate. Although, it is useful to take into account the traditional quantitative cost-benefit analysis, it is by no means sufficient for capturing the depth of the complexity of the problem in its entirety. Actually, traditional methods do not properly account for the flexibility inherent in most ICT investment decisions to launch them at the right time and the right scale. Real Options (ROs) present an alternative method since it takes into account the managerial flexibility of responding to a change or new situation in business conditions (Trigeorgis, 1996). Option thinking has been already applied to the broadband business field (Angelou & Economides, 2008, 2009a, 2009b). Also, options analysis in broadband business field and especially concerning broadband technologies upgrade, from ADSL to VDSL (Very High Data Rate Subscriber Loop), has been examined by Elnegaard (2002), EURESCOM P-901 (2000), FTTX News (2009), Kalhagen and Elnegaard (2002). Finally, Angelou and Economides (2005) provide a survey of ROs applications in the ICT field.

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After the deregulation of the telecommunications markets their structure has changed from monopoly to oligopoly. Hence, the ICT business opportunities do not belong exclusively to only one firm but may also be shared by other competitors (Smit & Trigeorgis, 2004; Trigeorgis, 1996; Zhu, 1999). Authorities that own physical infrastructure such as service utility companies (water, electricity, and transportation) and local municipalities experience competitive advantage, regarding building optical networks, against typical telecommunications operators. These advantages are mainly coming from the lower installation and implementation costs. Facility-based firms may consider a model of three basic stages regarding a new broadband business activity (Iatropoulos, Economides, & Angelou, 2004). The first stage is the dark fiber installation and optical passive network (PassNet) implementation, Fig. 1. The second stage is the fiber's activation, light the fiber by implementing active network (ActNet) and provide bandwidth services. Finally, the third stage is the services provision (SerPro) such as VoD (Video on Demand) or remote surveillance

This work treats these opportunities using Real Option (RO) thinking and applies Game Theory (GT) to model competition. Particularly, all these stages are opportunities that can be considered as ROs based on the basic business of dark fiber exploitation. Each business stage may involve different type and severity of competition. We focus on facility-based firms, normally utility companies or municipalities that own a number of physical resources.

The business perspective requires decisions regarding the geographical coverage, bandwidth, product quality and price, as well type of services to be offered. For each stage we may consider different type and severity of competition. The passive stage includes dark fiber, ducts and microducts. Especially, the passive stage is the main business opportunity for utility companies that own physical infrastructure for installing dark fiber along it. The active network includes all these equipment that light the fiber and provide capability for bandwidth dealing on the physical transmission mean. The active optical fiber network will provide wholesale access to Service Providers (telcos, Internet Service Providers, video providers etc.) or any third party which will want to lease a part of the funded infrastructure. The supported services (service provision) will be triple-play (Voice, Data and Video) and in the near future the four play (Plus Video, Mobile). The aim of the service provision stage is to offer services to end users. Table 1 summarizes the aforementioned discussion and the business

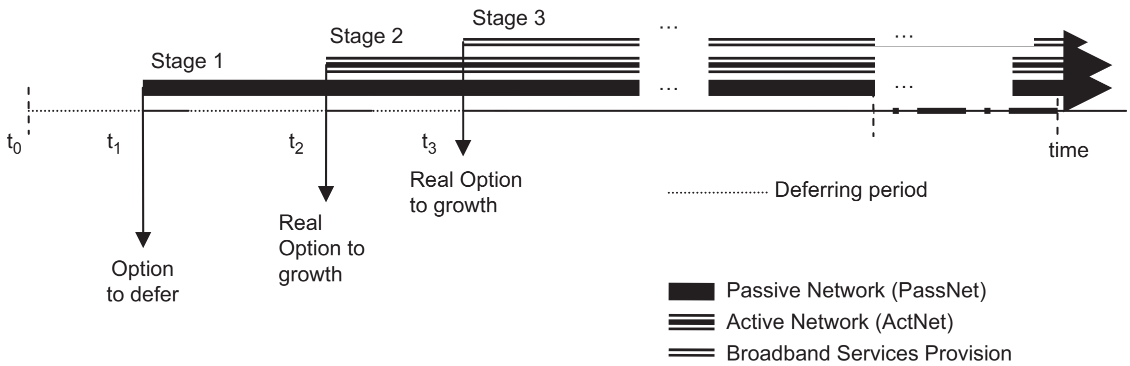

Fig. 1. Overall business in three stages and available growth options embedded.

Table 1
Business roles for broadband business field.

Business stage	Role	Description	Critical success factors	Comments
3	Service Provider	Internet, TV, Telephony and other services	Customer base, brand services platforms, marketing know-how	It requires a joint venture with an IT company, since utility companies and local municipalities present poor IT business culture.
2	ActNet	Operates the active network and provides equal access to service providers	Network operations know-how	It normally requires the involvement of Telecommunications experienced people. This can be realized by attracting the right people to the new company.
1	PassNet	Builds and owns the passive network	Funding for investment in passive network infrastructure	Normally, utility companies and municipalities may ensure funds from national or European Union sources for a passive network deployment.

roles and business stages which are available to utility companies. It also contains the critical success factors related to specific business activities.

Angelou and Economides (2009b) analyze the business perspectives of utility companies in the broadband business field and adopts quantity competition modeling for the PassNet stage and price competition for the ActNet stage. It considers that the business stages are available only for one period of analysis considering either to invest immediately or to abandon the business. In addition, Angelou and Economides (2009a) integrate ROs and GT perspectives and examines multi-period price competition in order to find the optimal ICT business strategy in terms of the time entry in the market and the service price. The analysis focuses on e-learning business activities. In the current paper we extent these works by focusing on the broadband field and more specifically the second (ActNet) and third (SerPro) stage of the available business model for utility companies. Particularly, we integrate ROs and GT perspectives and examine multistage and multi-period price competition, in a compound ROs perspective, in order to find the optimal ICT business strategy in terms of the time entry in the market and the service price. We consider two firms to be involved in the specific under investigation business entry. We assume that both players are rational, have access to the same amount of business related information as well as make the same understanding for this information. Our target is to find the overall business equilibrium for the two stages.

After the deregulation of the telecommunications markets, broadband business opportunities are supported by the state authorities who recognize that broadband technology can improve citizens' quality of life. Among others, European Commission (EC) indicated the necessity of broadband development in all member countries. It tries to offer to its citizens “an Information Society for all” providing a vision for the next years (https://ec.europa.eu/digital-agenda/en/telecoms-internet/telecoms; Kroes, 2012).

Concerning the situation in Greece key players in the Greek market are Vodafone, Cosmote, Wind Hellas, OTE, On Telecom, ForthNet, Hellas Online. Particularly, the broadband market benefits from extensive infrastructure-based competition. The dominant DSL platform has contracted in recent years as consumers have migrated to FTTH networks. This trend will become more pronounced in coming years, compounded by greater adoption of mobile broadband offerings as LTE networks depending on fiber backhaul take shape into 2013 BuddeComm's annual publication (2013). Competition in the fixed broadband market is improving, mainly driven by investments in local loop unbundling and resulted in a decrease of the incumbent operator's market share of retail broadband connections to 44% in January 2012 (down from 49% a year before). With regard to the fiber to the home project, the Government has revised its initial parameters according to a study provided by an external techno-economic consultant. The project intends the creation of a point to point (P2P) dark fiber open access network. The Greek incumbent continued its 3 year plan for the deployment of its new optical access network (GPON – Gigabit Passive Optical Networking – FTTC with the use of VDSL2 technology) in Athens, Thessaloniki and a limited number of other cities, which has been delayed pending approval of its wholesale bitstream offer (European Commission, Information Society and Media Directorate-General Greece, 2011).

Finally, in January 2012, the penetration rate of fixed broadband, in Greece, was 21.8% of the population, up 1.8% year-on-year but still 5.9% below the EU average of 27.7% (Digital Agenda for Europe, 2020a, 2020b). Greece, with a 1.8% year-on-year growth rate, is the fourth top country above the EU average growth of 1.2% Greece has 56.2% of fixed lines providing speeds of 10 Mbps and above. With regards to high and ultra fast speeds, no lines provide speeds equal or above 30 Mbps. More than half of broadband lines (56.2%) in Greece are in the range of 10 Mbps and below 30 Mbps.

On investments perspective, although the cost of broadband infrastructures has decreased, the required investments remain an obstacle for the private sector, while such investments may require coordination games (Mak and Zwick, 2010). Utility-based companies experience significant competitive advantages since they own a number of physical resources or installation rights that in overall decrease the optical fibers installation cost. Broadband in Greece is still at the early stages (Eurostat, 2008). However, government initiatives to increase the broadband penetration include the construction of fiber optics metropolitan networks in less developed regions. The owners of these infrastructures will be the municipalities which participate in this initiative. They will be free to make joint ventures with telecommunications private companies for ensuring the required experience in the specific business field (Iatropoulos et al., 2004).

Furthermore, the water supply and sewerage network operator in the second largest city of Greece, Thessaloniki, has announced its intention to enter into the broadband business field by installing optical fibers in the existing sewerage network (www.eyath.gr, 2012). Also, the city of Patras, which is the biggest municipality in the Region of Western Greece, and the third biggest city of Greece owns a Metropolitan Area Network connecting a large number of local authorities such as universities, hospitals and schools. Similar broadband metropolitan networks have been developed all over the world. Indicatively, we mention Sweden (Stockholm), Austria (Vienna), Spain (Catalonia), New Zealand (the city of Wellington), Netherlands (Amsterdam), USA (a group of cities in Utah) and Australia. Particularly, for Europe, 96 out of the 139 FTTx projects (FTTH, FTTB) involve municipalities and utility companies. For an overview of Fiber, European FTTH and Fiber backbone projects the interest reader is referred to Barua, Kriebe, and Mukhopadhyay (1991), Bouras (1999), and FTTX News (2009).

Finally, in regulation analysis field, Kelly and Rossotto (2012) provide a guide for policy makers, regulators, and other relevant stakeholders as they address issues related to broadband development. In addition, Cambini and Jiang (2009) survey the relevant theoretical and empirical literature on the relationship between regulation, at both retail and wholesale level, and investment in telecoms infrastructures. Finally, Bourreau, Cambini, and Hoernig (2012) analyze regulatory remedies suited to next generation access networks and study three issues: the migration from copper to fiber; the geographical segmentation of regulation; co-investment. Finally they propose some guidelines for policy makers.

The paper is organized as follows. Section 2 describes the model and the proposed analysis. Section 3 discusses a real life case study. Finally, Section 4 concludes, discusses limitations and presents suggestions for future research.

2. The proposed analysis and model

2.1. Analysis of demand under price competition

In the context of price competition, firms choose the quality and the price for their products, and the market determines the quantity. Service quality may be the bandwidth level provided quality-reliability of internet connection, or the quality of service support for failure connection problems. For example the incumbent operator may present much higher reliability in terms of internet connection and failure fixing time compared to the new telecommunication players that may provide lower prices for similar products in the beginning but showing lower quality of service afterwards. Also, service attribute may concern technical characteristics of the terminal equipment installed to the customer premises, such as router. The customers prefer high quality product, however they vary in their willingness to pay for it. Customers' types, according to their preference regarding products quality, are defined by the variable t_{sc}, which is uniformly distributed over the interval $[l_s,h_s]$, where $h_s > l_s > 0$ (please see Appendix for notations). Customers with $t_{sc}=h_s$ have the highest interest in the service/product for stage s. Customers with $t_{sc}=l_s$ have the less interest in the service/product. The density of customers for stage s, is N_s per unit of the type index. Hence, the total number of customers (overall market size) is $N_s(h_s-l_s)$.

Customers t_{sc} choose to buy the product if their utility (or net value) is positive. Particularly, we define the utility value for customer t_{sc} for product with quality attribute u_{sx} ($u_{sx}>0$) at the price p_{si} to be the difference between the value of this product V^{tsc} (i.e. quality or bandwidth, in our case) and the price p_{si} that the customer pays for stage s.

$$U^{t_{sc}}_{customer}(t_{sc}, u_{sx}, p_{si}) = V^{t_{sc}}(t_{sc}, u_{sx}) - p_{si} \tag{1}$$

where

$$\frac{\partial V^{t_{sc}}}{\partial u_{sx}} > 0, \quad \frac{\partial V^{t_{sc}}}{\partial t_{sc}} > 0$$

We adopt a specific function for utility estimation, proposed by Zhu (1999).

$$U^{t_{sc}}_{\text{customer}}(t_{sc}, u_{sx}, p_{si}) = \omega u_{sx} t_{sc} - p_{si} \tag{2}$$

The type t_{sc} customer will buy the product if the utility value is positive

$$t_{sc} \geq \frac{p_{si}}{\omega u_{sx}} = t_{sc0}$$

Since all customers in $[t_{sc0},h_s]$ have positive utility value and so will choose to buy the product, the total demand, D_{si} is

$$D_{si} = N_s(h_s - p_{si}/\omega u_{sx}) \tag{3}$$

We assume that the marginal cost of producing each unit is c_{si}. The development cost is $k_s {u_{sx}}^2$ (Barua et al., 1991). Actually, as the level of quality increases, it becomes even more difficult to further increase the service quality. Hence, the overall cost function is

$$C_{si} = k_s {u_{sx}}^2 + c_{si} D_{si} \tag{4}$$

where k_s is the coefficient of the development cost for stage s. The quadratic term represents that the marginal development cost increases as the service/product quality (e.g. bandwidth or fibers per connection) increases. For simplicity we assume that the marginal cost of c_{si} equals zero. In practice when the infrastructure is built, fiber passes outside home and the branching from the street to the main entry point of the building is implemented, the cost of customers' connection (mainly the activation of it) is very small. This assumption does not change the conclusions of our analysis. Finally, the operational profit is given by

$$P_{si} = p_{si} D_{si} - C_{si} \tag{5}$$

Angelou and Economides (2009a) estimate the equilibrium strategies of the firms for a single and two period game under price competition modeling. We extend the aforementioned analysis for both stages ActNet and SerPro adopting a compound real options model. For each stage we assume that the business opportunity remains valid for two periods, where at the end of the first period the firms are able to analyze the evolution of the market demand and business revenue.

2.2. Estimation of the business utility at each stage

We start the analysis from the last stage (SerPro). The possible decisions, for the duopoly case, for each player ($i=A,B$) are the following: invest for high quality (IN_{iHQL}), invest for low quality (IN_{iLQL}), defer investment for low quality (DF_{iLQL}), defer investment for high quality (DF_{iHQL}), and abandon (A).

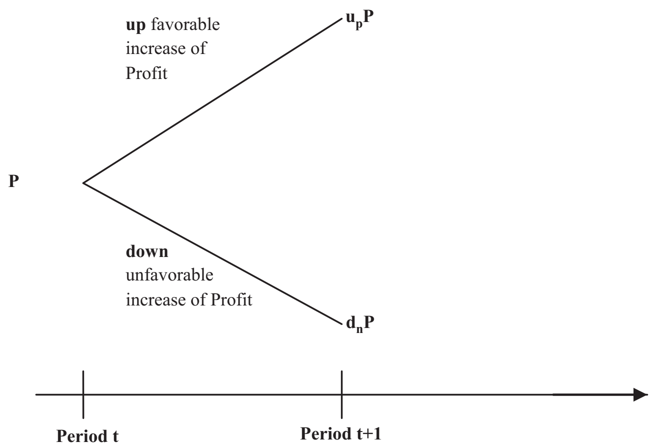

Fig. 2. Uncertain profit as binomial process.

Table 2
Game choices and investment payoff matrix.

A	B				
	IN_{BHQL} (invest high quality at $t=0$)	**IN_{BLQL} (invest low quality at $t=0$)**	**DF_{BHQL} (defer up to $t=T$ high quality)**	**DF_{BLQL} (defer up to $t=T$ low quality)**	**A_B (abandon)**
IN_{AHQL} (invest high quality at $t=0$)	No ROV (NPV)	No ROV (NPV)	ROV (ENPV)	ROV (ENPV)	Monopoly (No ROV)
	No ROV (NPV)	No ROV (NPV)	No ROV (NPV)	No ROV	
IN_{ALQL} (invest low quality at $t=0$)	No ROV (NPV)	No ROV (NPV)	ROV (ENPV)	ROV (ENPV)	
	No ROV (NPV)	No ROV (NPV)	No ROV (NPV)	No ROV (NPV)	
DF_{AHQL} (defer up to $t=T$ high quality)	No ROV (NPV)	No ROV (NPV)	ROV (ENPV)	ROV (NPV)	Monopoly (ROV)
	ROV (ENPV)	ROV (ENPV)	ROV (ENPV)	ROV (NPV)	
DF_{ALQL} (defer up to $t=T$ low quality)	No ROV (NPV)	No ROV (NPV)	ROV (ENPV)	ROV (ENPV)	
	ROV (ENPV)	ROV (ENPV)	ROV (ENPV)	ROV (ENPV)	
A_A (abandon)	M_{BO} (no OV)		M_{BT} (no OV)		No business at all

We consider a binomial process for the business operational profit (P), where u_p and d_n are the changes up to u_pP or down to d_nP according to a binomial process (Fig. 2). Especially, u_p and d_n are the multiplicative binomial parameters ($u_p>1$, $d_n<1$).

We use the backwards induction process to determine the sub-game perfect equilibrium and then use the dynamic programming technique to bring back the values from period $t+1$ to period t (Trigeorgis, 1996).

If the game has two periods left, then each firm (competitors) has to compare the payoffs from each of the possible decision combinations. If the investment decision is to invest immediately at t the overall business value is given by the Net Present Value (NPV) without any Real Options Value (ROV). On the other hand, if the decision is to defer up to $t=T$ (i.e. $t+1$) then the overall value is given by the Expanded NPV, which actually contains the ROV (Smit & Trigeorgis, 2004; Trigeorgis, 1996).

All the decision alternatives for a two-period business game are given in Table 2.

These choices exist for both business stages.

The expected Expanded Net Present Value (ENPV) for stage SerPro is given by the following

$$ENPV_{DF}=ROV_{SerPro}=\frac{1}{1+r}\left\{\begin{array}{l} q\max\left[P_{SerPro}{}^{u}-I_{SerPro},0\right]+ \\ (1-q)\max\left[P_{SerPro}{}^{d}-I_{SerPro},0\right]\end{array}\right\} \tag{6}$$

In the risk-neutral valuation of ROs, q is defined as the risk-neutral probability (Trigeorgis, 1996). The ENPV for high and low quality firms as well as monopoly conditions, adopting price competition modeling are given by Angelou and Economides (2009a, 2009b). Angelou and Economides (2009a, 2009b) analyze ENPV for waiting strategies according to the demand spectrum. The investment threshold, for stop waiting and acting, is a function of the uncertainty (measured by the volatility) of the market demand, the coefficient of the development cost and the overall investment infrastructure (one time) cost. The competitors will choose to wait more if the market demand is more volatile, and the infrastructure implementation costs higher. Particularly, the uncertainty of the market demand increases the ROV and provides arguments for waiting more. The competitor with the best quality attribute is able to charge higher prices and so experience higher revenues. The conclusion is that the size of the investment cost (one time – sunk cost) as well the market size (number and type of consumers) are key factors to the entry decision and so the investment equilibrium.

A similar analysis takes place for the stage of ActNet adopting compound ROs. In particular, the overall ENPV based on the compound options analysis, for the ActNet stage that contains the SerPro stage, is given by the following

$$ENPV_{ActNet+SerPro} = ROV_{ActNet} = \frac{1}{1+r}\left\{\begin{array}{l} q\ \max\left[P_{ActNet}{}^{u} - I_{ActNet} + ROV_{SerPro}, 0\right] + \\ (1-q)\max\left[P_{ActNet}{}^{d} - I_{ActNet} + ROV_{SerPro}, 0\right] \end{array}\right\} \tag{7}$$

The aforementioned equation is based on compound ROs analysis.

In particular, broadband bandwidth services provision profitability depends both on business condition for the specific and future investment opportunities. In order to analyze and solve the game we estimate the business value for each scenario of decisions between the two players (competitors). The solution of the game is the best combination of decisions for both players. The conclusion is quite obvious under full symmetry between players.

Under full symmetry between the players, the pay function is the same for both players. However, as the asymmetry between the players appears the pay offs are different for them indicating different strategies. It may be a subject of further work to adopt business asymmetries between the players as a more realistic case.

3. A case study

To illustrate the proposed methodology we apply it to an ICT investment decision for a growing Water Supply and Sewerage Company, which we refer to as WSSC to protect its identity and its projects. WSSC is interested in entering into the broadband business field and exploiting its physical infrastructure (water and sewerage pipes). The company examines the possibility of setting up a subsidiary company named NewTelco Services and entering the telecommunications business being involved with both stages ActNet and SerCo for broadband business. NewTelco Services may undertake the following roles:

- PassNet: it builds and owns the telecommunications access infrastructure which includes passive connection – supply and install ducts, conduits & fiber to the building.
- ActNet: it activates and operates the active network acting as a wholesale bandwidth provider which includes active connection – supply and install Optical Network Termination (ONT) at the building, service/line activation – connected building ready to receive telecommunications services.
- SerCo: it provides network services to deliver telecommunications services to their customers (i.e. the connected homes/ business premises).

The overall competition of the WSSC in the broadband business plans to deploy its own fiber network. Hence, WSSC with its subsidiary NewTelco Services needs to be the first to the market deploying a fiber network in the area. Also, it should work closely with ISPs and other providers to address their requirements concerning methods of interconnection as well network reliability and redundancy aspects.

By waiting, WSSC expects that uncertainties, related to the acceptance of broadband services in the region, and the organizational capabilities of it, would be resolved. The acceptance of these services (i.e. customers demand) is actually modeled in the current analysis. By waiting, WSSC could learn more about the potential returns on such investments. For example, the acceptance rate for such services might increase as customers become more aware of these services. In parallel, WSSC could take actions to lower its market entry risk (e.g. by seeking corporate alliances for joint exploitation of the specific regional market).

With these concerns in mind WSSC addresses to the question: “should WSSC wait to enter the broadband market? or proceed immediately exploiting its competitive advantage?”

A two-player game is considered where one player is WSSC and the other player is the rest of the competition. The numbers are fictitious in order to protect NewTelco Services business. However, they are based on extensive discussion with the company's upper level management as well as the potential competitors.

The aspects to be taken into account for the selection of the area of interest include demographic, density and income characteristics of the customers. WSSC focuses on the geographical area with the expected higher interest for broadband business.

WSSC examines to invest on 50 km streets optical fiber for connecting incumbent operator local switching centers, to implement the backbone network. Along that way there are 200 customers premises/km. So, the overall market size is 10,000 customer premises for FTTH connection. Assuming an average penetration of 40% along the 10 years period of analysis, the overall customers demand is 4000 FTTx connections. In this case study we examine the business of offering active optical fiber and broadband services in the specific area acting as a new telecommunication comer in the broadband business field. We do not examine the business perspective of providing wholesale broadband services in telecommunication operators.

In our analysis we consider that dark fiber installation (PassNet) and activation of it (ActNet) takes place at once, adopting the aforementioned analysis for the ActNet of the previous part. The initial infrastructure cost includes ducts, dark fiber installation and activation of it along the streets in the area of interest, while in the next stage the broadband service provision (SerPro) takes place.

The infrastructure cost IActNet that contains also the cost of passive dark fiber installation can be analyzed in two parts. The first part is the cost of installing the network along the street (optical fiber past), while the second part is the cost of connecting the customers's promises to the optical fiber network, passing from the street in front of them.

For our analysis, we estimate the total cost of optical fiber passive and active equipments to be 750€/customer (www.broadband.cti.gr).

The values of the parameters for the case study are given in the third column of the Table A1 (Appendix). For simplicity, we consider zero taxes and depreciation so that the operating cash flows are equivalent to the operating profits.

We examine the following scenarios: Invest at $t=0$ or Defer at $t=2$ for the PassNet and the ActNet stages and Invest at $t=2$ or Defer at $t=4$ for SerPro stage. In particular, we assume that the SerPro is available for the WSSC after two years of the ActNet implementation. For simplicity, we assume very small building time for the business stages, practically 6 months, while the commercialization phase for each stage starts at the same year.

For the estimation of ROV we adopt the binomial model focusing on one-step diffusion process. The binomial model is the most widely applied especially in cases of multi-options analysis (Smit & Trigeorgis, 2004; Trigeorgis, 1996). In practice, the single-step diffusion analysis is appropriate for investments where management has limited opportunity to influence the outcome of the investment and reviews investment status every year. The NPVs and ENPVs for the case study are presented in Tables 3 and 4.

Table 3
Pay offs for stages ActNet and SerPro strategies for each part (basic scenario of investment cost).

Stage[a]: ActNet (IN at $t=0$ or DF at $t=2$)					**Stage[b]: SerPro (IN at $t=2$ or DF at $t=4$)**				**Overall Business Value**
σ	**100%**	**80%**	**40%**	**10%**	**σ**	**80%**	**40%**	**10%**	**$\sigma=80\%$**
IN_M	4721	4721	4721	4721	**IN_M**	6721	6721	6721	**10,818**
DF_M	5734	5260	4729	4729	**DF_M**	6723	6723	6723	**11,420**
IN_{HQL}	3039	3039	3039	3039	**IN_{HQL}**	5039	5039	5039	7,609
					IN_{LQL}	−622	−622	−622	2,475
					DF_{HQL}	5041	5041	5041	7,611
					DF_{LQL}	17	0	0	3,056
					A	0	0	0	0
IN_{LQL}	−2622	−2622	−2622	−2622	**IN_{HQL}**	5039	5039	5039	1,948
					IN_{LQL}	−622	−622	−622	-3,186
					DF_{HQL}	5041	5041	5041	1,950
					DF_{LQL}	17	0	0	-2,605
					A	0	0	0	-2,622
DF_{HQL}	4340	3930	3047	3047	**IN_{HQL}**	5039	5039	5039	7,606
					IN_{LQL}	−622	−622	−622	3,771
					DF_{HQL}	5041	5041	5041	**8,083**
					DF_{LQL}	17	0	0	3,937
					A	0	0	0	3,930
DF_{LQL}	0	0	0	0	**IN_{HQL}**	5039	5039	5039	1,944
					IN_{LQL}	−622	−622	−622	0
					DF_{HQL}	5041	5041	5041	2,421
					DF_{LQL}	17	0	0	0
					A	0	0	0	0
A	0	0	0	0	…	0	0	0	0

[a] Values at $t=0$ ($\times$ 1000€).
[b] Values at $t=2$ ($\times$ 1000€).

Table 4
Pay offs for stage ActNet (for double investment cost).

Stage[a]: ActNet (IN at $t=0$ or DF at $t=2$) $I_{ActNet}=6000$				
σ	**100%**	**80%**	**40%**	**10%**
IN_M	1721	1721	1721	1721
DF_M	5068	4416	2844	1736
IN_{HQL}	39	39	39	39
IN_{LQL}	−5623	−5623	−5623	−5623
DF_{HQL}	3673	3086	1637	258
DF_{LQL}	0	0	0	0
A	0	0	0	0

[a] Values at $t=0$ ($\times$ 1000€).

Table 5
Pay offs for stage ActNet (for different underline asset).

Stage[a]: ActNet (IN at $t=0$ or DF at $t=2$) $I_{ActNet}=6000$ (two types of customers and 3000 each type) (Different business underline asset value)				
σ	100%	80%	40%	10%
IN_M	11,373	11,373	11,373	11,373
DF_M	13,069	12,044	11,400	11,400
IN_{HQL}	7587	7587	7587	7587
IN_{LQL}	−5150	−5150	−5150	−5150
DF_{HQL}	9931	9052	7602	7602
DF_{LQL}	0	0	0	0
A	0	0	0	0

[a] Values at $t=0$ ($\times$ 1000€).

Table 6
Pay offs for stage ActNet (for revenues and investment costs difussion process).

Stage[a]: ActNet (IN at $t=0$ or DF at $t=2$) $I_{ActNet}=6000$ (uncertainty modeling for both investment cost and business underline asset)				
σ[b] (For revenues and investment cost)	100%	80%	40%	10%
IN_M	1721	1721	1721	1721
DF_M	7083	5336	3110	1811
IN_{HQL}	39	39	39	39
IN_{LQL}	−5623	−5623	−5623	−5623
DF_{HQL}	5030	3597	1644	359
DF_{LQL}	143	0	0	0
A	0	0	0	0

[a] Values at $t=0$ ($\times$ 1000€).
[b] Correlation between cost and revenues is 0.

In addition, we extent the analysis by adopting different underline asset (business revenue) for stage ActNet as, Table 5. In addition, the paper considers multidiffusion process for the infrastructure investment cost and business revenues for stage this stage ActNet. The log transformed binomial model is adopted in discrete time domain (Gamba & Trigeorgis, 2001). The business value adopting both revenues and investment cost uncertainty and defer strategy is significantly higher that the case of single revenues diffusion process, Table 6. We consider one time step multi-diffusion process. Multiple time steps result to increased granularity and so to increased accuracy in the results. Though the complexity of the model is increasing dramatically we capture more efficiently the additional dimension of competition entry.

Comparing NPV and ENPV we can see that in case of NPV close to zero the ENPV shows higher enhancement (ROs value) as seen in both Tables 3 and 4 for stage one, for different values of investment cost.

Under price competition the firm with the higher quality of the broadband bandwidth provision will provide higher profits.

As we can see the higher quality product/service ensures higher profitability. In particular, the business performance for each stage and as a whole shows higher values for the monopoly case, as expected. However, even for the monopoly case the strategy to defer investment for both cases presents higher profit compared to the immediate investment of each stage when it is available for the WSSC.

In case of duopoly price competition, deferring for both stages to activate business and offer higher quality services compared to the competition is the optimal strategy. In particular, for the waiting strategy and invest at the end of the period where the investment is available proving high quality service presents 8,083,000€ ENPV. If low quality capability is available then the waiting strategy is the only realistic scenario.

Especially, for WSSC broadband business, high quality could mean:

- Provision of real FFTx connection and not VDSL connection (here, competitor is the incumbent operator since it has the last mile competitive advantage).
- High bandwidth for the last mile connection from the neighborhood concentrator to the customer's office and home.
- Capability of integrating various utilities services in one platform, such as water, electricity and gas consumption for the third stage of the business.

The capability of the WSSC to implement the last mile fiber network (which is a difficult task for its competitor), provides the option to be the higher quality firm for broadband connections in the area of interest. Particularly, WSSC should exploit its advantage for real FFTx connection. This advantage is known to its competitors that normally should plan for the most conventional VDSL connections.

In conclusion, WSSC should offer higher level of services and charge them with higher price than its competition. The higher the business uncertainty is, the more profitable to delay the investment is. While the lower it is, the immediate investment becomes more attractive.

4. Discussion and future research

Senior finance executives are becoming increasingly aware of the need to view infrastructure investments as well growth opportunities based on this infrastructure as ROs. ROs have already been applied for evaluation of ICT and more particularly broadband investments. In practice, managers may identify stages of overall business, and identify options mapped onto these stages. However, the single option analysis experiences criticism concerning the existence of competition which may cause a significant decrease and even more elimination of the option value.

Analytically, this paper proposes a framework for broadband business analysis taking into account broadband business developed in stages, and each one of them experiences different competition characteristics. Although extensive analysis of basic price and quantity competition games is already present in the basic industrial organization literature, this paper aids in the modeling dimension beyond that by introducing a compound competition perspective.

The delay for business implementation, as proposed by single ROs analysis, is not necessarily the result of flawed or irrational managerial decision making. Sometimes, deferring an investment may be optimum, while some other times the immediate implementation is the best solution. The former is mainly applied to single ROs analysis without competition threat; while the latter seems more realistic in case of competition treat.

The primary contribution of this paper is the provided solid evidence that the broadband business treated in stages, with specific competition characteristics, can be modeled by ROs which influence decision makers to rationally choose the time, scale and characteristics of the products (services) provided.

The key implication of the paper is that instances of deferring before acting that may seem to be irrational decisions based on traditional methods of evaluating projects may in fact be quite rational when the value of options is considered. In addition, options value may be even higher if both revenues and investments cost uncertainty modeling takes place. In particular, investment cost, especially for infrastructure, may experience significant uncertainty related to construction conditions and implementation technology efficiency in projects real conditions. However, competition presence causes decision makers to rush equilibrium, adopting smaller deferring period.

The managerial implications of our approach and analysis are mainly two-fold. First, it provides the means to methodically identify broadband business characteristics and especially competition ones. Broadband business is based on an infrastructure platform initialization, which contains future growth options to be exercised if business conditions are favorable. Secondly, once the business stages had been identified, management wants a rational and quantitative method for estimating the business value under the competitive conditions.

Managers typically adopt an intuitive approach favoring projects that promise flexibility in enabling new projects in the future. However, this is usually a very subjective exercise which does not take into account the competition threat.

The proposed compound options analysis provides the analytical methodology that objectively considers the immediate and future value of the broadband business.

Another managerial implication of the proposed analysis is that until utility companies are able to overcome demand uncertainty by adopting ROs philosophy and deferring investment. This philosophy proposes the waiting strategy instead of acting immediately if expected customers demand is below a specific threshold.

The model and the methodology focus on a two-player game in order to make the presentation of the proposed model clear and simple. They could be easily extended to more players. In telecommunications markets, there are normally two or three strong players and a number of weaker players that normally follow the strong ones. In the case study, a two-player game is also considered; one player is the firm of interest and the other is the rest of competition as one entity.

The proposed model could be applied to other real cases in the ICT business field. Previous studies have applied ROs for evaluating ICT investments. However, the option analysis experiences criticism concerning the need for the parameters' quantification of the ROs models. An extension of our work can include multi-criteria taking into account both quantitative and qualitative factors based.

5. Conclusion

This paper models business activities for municipalities and utility companies in the broadband business field adopting multistage price competition modeling. It models competition and provides an overall analysis for the whole business, which can be divided in stages. The aim is to estimate the strategies performance considering a two-player business game. Also, a real business case is analyzed by using the proposed analysis. The results of the analysis prove that delay of investment is more attractive for high uncertainty business even if there are monopolistic conditions in the market Also, the quality of the product (service) provision is critical for the profitability and optimal time to invest. As a future work, the asymmetry between firms is a realistic requirement to be considered, especially concerning investment cost and business experience. Finally, real world business cases should test the proposed model to verify its suitability in the specific decision field.

Appendix A

See Table A1.

Table A1
Notations used in our model.

Notation	*Definition*	*Values of the parameters in the case study*
s	Available business stages (s: ActNet, SerPro)	Two stages considered in the analysis as well as the case study
t	Time where the investment is available to be performed and decision analysis takes place	
D_{si}	Customers demand at time period t for business stage (s: ActNet, SerPro) and firm i (i=A,B).	4000 FTTx dark fiber connections
p_{si}	Price of service (product) offered for stage by firm i	
P_{si}	Business operational profit for stage s for firm i	
d_nP_{si}	Decrease of P_{si} moving down by d_n (binominal process) from period t to $t+1$	
u_pP_{si}	Increase of P_{si} moving up by u_p (binominal process) from period t to $t+1$	
I_{si}	Business infrastructure cost (one-time cost) at the time period t for stag s and firm i	I_{ActNet}=3,000,000€ (6,000,000€) I_{SerPro}=1,500,000€
r	Discount factor (the same discount factor is assumed for both stages)	5% (We assume 10 years of business operation period)
NPV_{si}	Net Present Value of business opportunity where no ROV exists for stage s and firm i	
$ENPV_{si}$	Expanded Net Present Value of business opportunity which contains the ROV for stage s and firm i	
ROV_{si}	Real Option Value (ROV) of business opportunity, stage s for firm i	
l_s	Lower index of customers type of the market being interest to by service (product) with specific quality attributes for stage s	
h_s	Higher index of customers type of the market being interest to by service (product) with specific quality attributes for stages s	2 (we consider two types of customers i.e. domestic customers, and business-domestic customers)
N_s	Number of customers for each customer type for stage s.	2000 (3000)
C_{si}	The overall operational cost function for stage s and firm i.	
k_s	The coefficient of the development cost (assume the same for both stages)	1
c_{si}	Marginal cost of service (product) offered for stage s by firm i	0
t_{sc}	Type of consumers for stage s	
u_{sx}	Service quality of level x for stage s (x=1,2), $u_{s2} > u_{s1}$	
$U^{tsc}{}_{customer}$	Utility value of the product for customers t_{sc}	
ω	Coefficient factor that is related to the service (product) value for the customer	1
σ	Uncertainty of business profit for each stage	10%, 40%, 80%, 100%

References

Angelou, G., & Economides, A. (2005). Flexible ICT investments analysis using real options. *International Journal of Technology, Policy and Management*, *5*(2), 146–166.

Angelou, G., & Economides, A. (2008). A real options approach for prioritizing ICT business alternatives: A case study from broadband technology business field. *Journal of the Operational Research Society*, *59*(10), 1251–1340.

Angelou, G., & Economides, A. (2009a). Price competition in ICT business. *Paper presented at 4th mediterranean conference on information systems* (*MCIS*). Athens, Greece, 25–27 September.

Angelou, G., & Economides, A. (2009b). Staged competition modeling in broadband business field. *Paper presented at ninth IASTED international conference on wireless and optical communications* (*WOC 2009*). Banff, Alberta, Canada. IASTED, July 6–8.

Barua, A., Kriebe, C., & Mukhopadhyay, T. (1991). An economic analysis of strategic information technology investments. *MIS Quarterly*, *15*(3), 313 (ABI/INFORM Global).

Bouras, C. (1999). *Fiber optical networks for municipalities in Greece: Myths and realities*. Retreived on 1/8/2009 from: ⟨http://interreg-broadband.cti.gr/download/FTTH_Myths_Reality_AIT11042008_Bouras.ppt⟩.

Bourreau, M., Cambini, C., & Hoernig, S. (2012). ex ante regulation and co-investment in the transition to next generation access. *Telecommunications Policy*, *36*(5), 399–406.

BuddeComm's annual publication (2013). *Greece – Telecoms, IP Networks, Digital Media and Forecasts*. Retrieved on Sunday 5th of May 2013 from ⟨http://www.budde.com.au/Research/Greece-Telecoms-IP-Networks-Digital-Media-and-Forecasts.html⟩.

Cambini, C., & Jiang, Y. (2009). Broadband investment and regulation: A literature review. *Telecommunications Policy*, *33*(10–11), 559–574.

Digital Agenda for Europe (DAE). (2020a). Retrieved on November 1st 2012, from ⟨https://ec.europa.eu/digital-agenda/en/telecoms-internet/telecoms⟩.

Digital Agenda for Europe (DAE). (2020b). Greece report. Retrieved on Sunday 5th of May 2013 from ⟨https://ec.europa.eu/digital-agenda/en/scoreboard/greece⟩.

Elnegaard, N. (2002). How to incorporate the value of flexibility in broadband access network rollout investment projects. *Paper presented at 41st European telecommunications congress* (*FITCE*). Genoa, Italy.

EURESCOM P-901. (2000). Investment analysis modeling – Investment analysis under uncertainty. In *Project Deliverable* 2, Vol. 4.

European Commission, Information Society and Media Directorate-General Greece. (2011). *Telecommunication market and regulatory developments, June* 2012. Retrieved on May 1st 2013 from ⟨https://ec.europa.eu/digital-agenda/sites/digital-agenda/files/EL_Country_Chapter_17th_Report_0.pdf⟩, ⟨http://broadband.cti.gr/el/download/P93_P3.1_EAITY_FINAL.pdf⟩ retrieved on March, 22nd 2009.

Eurostat. (2008). Retrieved on: 1/8/2009 from: ⟨http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1090,30070682,1090_33076576&_dad=portal&_schema=PORTAL⟩.

EYATH S. A., 2012. *Call of interest for installing optical fibers along the sweage pipes*. Retrieved on October 1st from ⟨http://www.eyagh.gr⟩.

FTTX News, Retrieved on 1/8/2009 from: ⟨http://fttxnews.blogspot.com/search/label/FTTP⟩.

Gamba & Trigeorgis, L., (2001). A Log-transformed binomial lattice extension for multi-dimensional option problems. *Presented at the 5th Annual conference on real options, anderson school of management*. UCLA: Los-Angeles.

Iatropoulos, A., Economides, A., & Angelou, G. (2004). Broadband investments analysis using real options methodology: A case study for Egnatia Odos S.A.. *Communications and Strategies*, *55*, 45–76.

Kalhagen, K., & Elnegaard, N. (2002). Accessing broadband investment risk trough option theory. *Telektronikk Magazine*, *2*(3), 51–62.

Kelly, T. & Rossotto, C. (2012). *Broadband strategies handbook*. Coordinated by Telecommunications Management Group, Inc. 2012 International Bank for Reconstruction and Development/International Development Association or The World Bank. Retrieved on 20th November 2012 from ⟨http://broadbandtoolkit.org/Custom/Core/Documents/Broadband%20Strategies%20Handbook.pdf⟩.

Kroes, N. (2012). *Connecting Europe: Fast broadband for all broadband world, Forum/Amsterdam, 16 October 2012*. Retrieved on November 15th 2012, from ⟨http://europa.eu/rapid/press-release_SPEECH-12-731_en.htm⟩.

Mak, V., & Zwick, R. (2010). Investment decisions and coordination problems in a market with network externalities: An experimental study. *Journal of Economic Behavior & Organization*, *76*(2010), 759–773.

Smit, J., & Trigeorgis, L. (2004). *Quantifying the strategic option value of technology investments*. Working Paper, Erasmus University Rotterdam & University of Cyprus.

Trigeorgis, L. (1996). *Real options: Managerial flexibility and strategy in resource allocation*. Cambridge, Massachusetts, London, England: The MIT Press.

Zhu, K. (1999). *Strategic investment in information technologies: A real-options and game-theoretic approach (Doctoral Dissertation)*. CA: Stanford University.