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Broadband business by utilities infrastructure exploitation: A multistage competition model

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ABSTRACT

A promising broadband business opportunity is the exploitation of the physical resources owned by municipalities and utility-based firms. In this study, the new broadband business opportunities owned by these authorities are analyzed through the development of a decision analysis model. The proposed model analyzes the broadband business into stages, integrates real options and game theory and provides business equilibrium in terms of the time of entry in the market, quantity offer and price definition. Finally, a real world case study is discussed showing how the model can be applied.

1. Introduction

In the new era of the telecommunications business with a large number of potential investors, the Information and Communication Technologies (ICT) service providers should seek access network solutions with even more bandwidth. So far, the most viable solution for high bandwidth provision, especially in access networks, is the optical fibers technology. Particularly, the installation of the optical fibers and their commercial exploitation may be a very challenging business activity. Especially, after the telecommunication market deregulation, authorities that own physical infrastructure such as service utility companies (e.g. 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. In particular, existing physical infrastructure, such as sewerage pipes, can be used for installation of optical fibers inside it. The installation cost of optical fibers inside the pipes is significantly lower than the cost of the typical method along the street (Angelou & Economides, 2011).

Facility-based firms may consider a model of three basic stages, for broadband business (Iatropoulos, Economides, & Angelou, 2004). The first stage is the Dark Fiber (DF) installation and optical network implementation, operation and maintenance. The second stage is the DF activation, light the fiber, and provide bandwidth services. Finally, the third stage is the services provision such as VoD (Video on Demand) or remote surveillance (see Fig. 1). This work treats these opportunities using real option (RO) and applies game theory (GT) to model competition. Particularly, all these stages are opportunities for utility companies that can be considered as defer or growth options based on the basic business of the dark fiber exploitation. However, the options to implement these business stages experience competition threat that can

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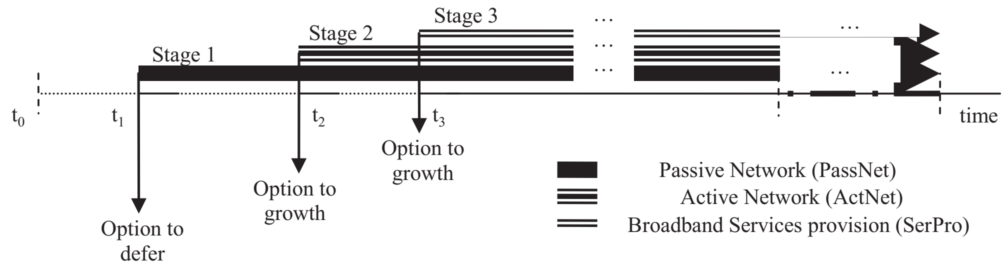

Fig. 1. Overall business in three stages and available growth options embedded.

eliminate or even more degrade them (Trigeorgis, 1996, 1999). Also, each business stage may involve different type and severity of competition.

In general, there are three dimensions in competition modeling: market structure, subject of investigation and nature of competitive actions (Trigeorgis, 1996). Analytically, depending on the number of competitors, the market structure can be either a monopoly, or an oligopoly or a perfect competition if many market participants are present. In addition, a decision maker can be interested either in the optimal decision of the single firm or in the outcome of the decisions of all market participants.

The competition is modeled as exogenous if the firm has no means to influence the other competitors' actions. This is more realistic in perfectly competitive markets with many market participants. In oligopolistic markets, actions taken by the firm may likely result in strategic reactions by its competitors. In this case competition should be modeled as endogenous and requires the combination of ROs and GT (Angelou & Economides, 2008a; Smit & Trigeorgis, 2004; Trigeorgis, 1996; Zhu, 1999;, Zhu & Weyant, 2003a, 2003b). This work focuses on the latter.

After the deregulation of the telecommunications markets their structure has changed from monopoly to oligopoly. The ICT business opportunities do not belong exclusively to only one firm but may also be shared by other competitors.

The main challenge for a potential provider (investor) is to roll out its business activity at the right time and the right scale taking in parallel into account the threat from competition that can eliminate it. 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. 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 ICT field (Angelou & Economides, 2008a, 2008b; Benaroch, 2002; Kester, 1984; Kumar, 2002). Also, options analysis in the broadband business field and especially concerning broadband technologies upgrade, from ADSL (Asymmetric Digital Subscriber Loop) to VDSL (Very High Data Rate Subscriber Loop), have been examined by Elnegaard (2002), Elnegaard and Stordahl (2002), Eurescom P-901 (2000), d'Halluin, Forsyth, and Vetzal (2002), and Kalhagen and Elnegaard (2002). In addition, Angelou and Economides (2005) provide a survey of ROs applications in the ICT field.

Furthermore, Rokkas, Katsianis, and Varoutas (2010) apply real options analysis (ROA) to perform a techno-economic study of fiber-to-the-cabinet/very high bit rate digital subscriber line (FTTC/VDSL) and fiber to the home (FTTH) deployments. Also, Verbrugge et al. (2011) present an in depth analysis of the FTTH total cost of ownership comparing different possible business models both qualitatively and quantitatively. Finally, Tahon et al. (2011) investigate business cases for 3G and WiFi operators and indicate how to model the specificities for commercial versus public players. They adopt game theory to investigate the investment options of municipal players in the specific field.

However, an ICT business opportunity is shared by several competitors (potential investors–players). Despite its importance, competition has been typically ignored in most of the ROs literature. Only a few recent papers have started to address this issue. Among others, Angelou and Economides (2009b, 2011), Grenadier (1996, 2002), Joaquin and Butler (2000), Perotti and Kulatilaka (1998), Smit and Trigeorgis (2004), Trigeorgis (1996), and Zhu and Weyant (2003a, 2003b) provided various treatments of the interplay between real options and game theory.

Viewing broadband business under the ROs perspective, this paper develops a model for evaluating such business in the joint presence of uncertainty and competition. The broadband technology industry characteristics are taken into consideration in the model. The proposed analysis aims at finding answers to the following questions:

- which stages of the broadband business are available at the utility firms and municipalities?
- what kind of competition is experienced by the potential investor at each stage?
- what are the optimum time entry into the market and the scale to implement each stage of the overall broadband business?

This paper extends the work of Zhu (1999) and Zhu and Weyant (2003a, 2003b) by considering multistage, multi-type competition modeling in a compound basis, which is related to compound ROs perspective. Particularly, Zhu focuses on new technology adoption in the production process for reducing the marginal operational production cost. The current paper focuses on the broadband business field where the business product is directly the ICT content and it is not the mean for increasing the production efficiency. It also extents the Angelou and Economides (2011) work, which integrates compound ROs and GT techniques and adopts price competition analysis, for the broadband services provision, in order to find the optimal business strategy. Particularly, they examine the stages of active fiber exploitation and broadband services provision and analyze a price competition game. The current work models the competition for the stages of dark fiber and active fiber exploitation adopting multistage and multitype competition modeling. Finally, it extends the work of Angelou and Economides (2008a), which adopts exogenous competition modeling in a compound basis for the ICT business activities, and estimates the optimum business deployment. The current paper adopts endogenous competition modeling, fact which is more realistic in the new telecommunications era.

The paper is organized as follows. Section 2 describes the proposed model and the analysis. Section 3 discusses a real world case study. Section 4 discusses managerial implications and provides suggestions for future research. Finally, Section 5 concludes.

2. Research model

The analysis focuses on a two players' game in order to make the presentation of the model clear and simple. The more players included in the game the more complicated the model becomes and each of the players has to define many business alternatives to be considered in the decision game. However, the model and the methodology can easily be extended. Furthermore, in telecommunications markets there are normally two–three strong players and a number of weaker players that normally follow the strong ones. A perspective would be to consider one player to be the firm of interest and the other player to be the rest firms as one entity.

Fig. 2 describes the proposed research methodology. Part A deals with the factors that define the overall business value as well as the assumptions required for their applicability to the broadband business field. Such factors are the service demand, the investment cost (infrastructure fixed cost and operational cost), and the revenues produced. In part B, the business utility for each stage as well as for the overall business and for each firm, according to the decision combinations, are estimated for finding the solution of the model.

2.1. Definition of the overall business opportunity and the game

The paper focuses on facility-based firms, normally utility companies, as well as municipalities that own a number of physical resources. Such resources may include transportation networks, sewerage and water pipes, electrical wires poles and pylons. The overall analysis, and the possible involvement of a utility company, is based on two perspectives or dimensions: business and network.

The business perspective requires decisions such as the geographical coverage, bandwidth, product quality and price, as well as type of services to be offered. Regarding the business perspective the authors consider three layers: the passive network (PassNet), the active network (ActNet) and the service provision. For each layer they may consider different type

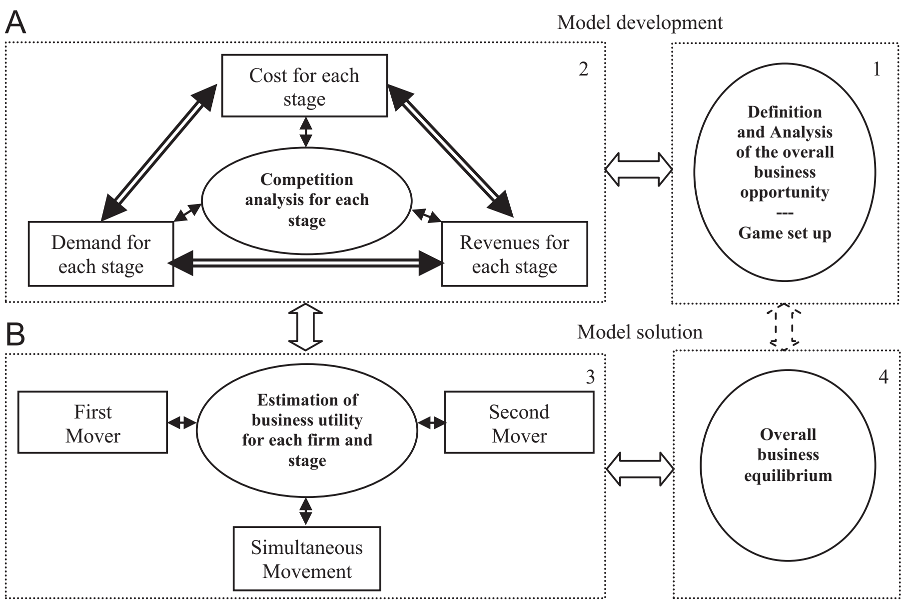

Fig. 2. Structure of the research methodology.

and severity of competition. The passive layer includes dark fiber, ducts and microducts. Especially, the passive layer 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.

Finally, the aim of the service provision layer is to offer services to end users. Table 1 summarizes the business roles and business stages, which are available to utility companies according to the aforementioned discussion. It also presents the critical success factors related to specific business activities.

Regarding the network perspective, they also consider three layers: backbone (main), distribution and access network (Fig. 3). Each network layer is composed by a number of corresponding nodes.

Regarding a national level perspective, the main network layer may involve intercity and interarea connections. A typical example of backbone implementation with optical fibers was discussed by Iatropoulos et al. (2004). For a metropolitan area network (MAN), the main network nodes compose the higher network topology. Typical examples of connections may be Internet Service Providers (ISPs) connections with incumbent central exchanges.

Typical examples of distribution nodes are local incumbent concentrators, curbs, from which the last mile connections are implemented. In this case optical fibers installation may concern to FTTC (fiber to the curb). Finally, the access network consists of the access nodes. A number of buildings are connected to an access node through a fiber cable, FTTH/B (fiber to the home/building).

2.1.1. The game

Two identical firms may enter the broadband business field in the deregulated telecommunications market. There is no prior leader in the market in the specific business field. Particularly, though the incumbent operator owns competitive advantage in covering broadband services needs, in practice FTTx (fiber to the x) connections have been not fulfilled yet. It is assumed 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. Firms (competitors) watch and analyze, for each stage of the business game, the overall market demand and recognize the market size and their optimum entry point into the market. According to the market demand there may be space for one, for two, or for none of the players to enter the market.

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

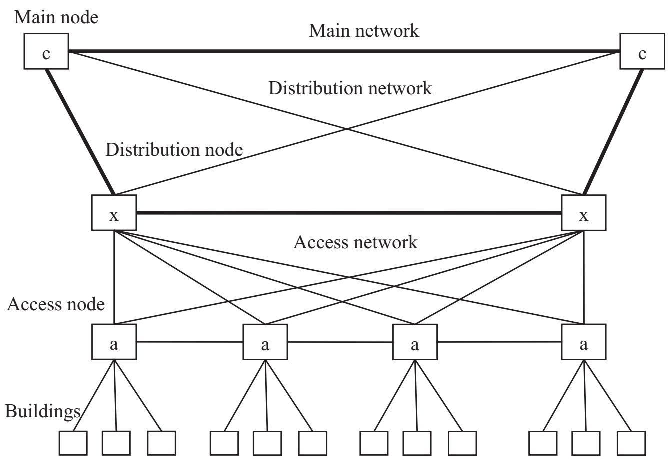

Fig. 3. General network architecture.

2.2. Competition analysis at each stage

2.2.1. The proposed competition modeling for these opportunities

The industrial organization literature has investigated circumstances under which different type of competition is more likely to occur (Trigeorgis, 1996). In the case where fixed costs are all paid before sales take place and the firms have capacity to fill many more orders than they may get, price competition is likely. One firm's temptation to undercut its rival's price and capture all the market, which underlies Bertrand's model, is present only when that firm has the capacity to serve the whole market.

In other cases, where the production process takes a long time, firms may commit themselves to some level of output, and then sell it for what they can get. In this case, the competition is in quantities. Such case might be the development of a dark fiber network at distribution and especially access network layer, while the quantity parameter to be decided by the firms might be the geographical coverage of it.

(1) *Dark fiber installation–infrastructure decision–passive network*: In this stage, firms choose the geographical area (coverage) of the dark fiber deployment. The authors consider it as quantity competition, because such investment takes a long time and so firms prefer to commit themselves with a specific quantity (here, they assume geographical coverage). Quantity competition equilibrium is estimated by the typical game theory analysis for both simultaneous and sequential decisions (Trigeorgis, 1996).
(2) *Active equipment installation*: In the second stage, the firms choose capacity (size of routers, switches, portion of fiber to light, etc.) for each market segment; this capacity choice determines the maximum number of telecommunications providers, households and business customers in the specific market's segment that can be finally served. Firms may install different capacities in different segments. The paper considers price competition for a more reliable decision analysis process (Angelou & Economides, 2011). It assumes that after having decided for the geographical coverage and the dark fiber installation, active equipment to light it, may be practically easily existing providing so high capacity to fill it.
(3) *Service and content provision*: In the third stage, the firms choose products and services with specific attributes to offer to the customers. Such services might be double or triple play ICT services with specific bandwidth values and specific service attributes. Price competition is considered. Particularly, competitors choose price and offer service to consumers who choose whether or not to buy service taking into consideration these prices; consumption takes place and profits are realized. Hence, the firms choose the price of the products/services offered and the customers choose the quantities.

In conclusion, the physical infrastructure competition (dark fiber) is modeled as quantity competition. On the other hand, competition in bandwidth and services provision is modeled as price competition.

Regarding the network architecture perspective, the quantity selection may involve different perspectives for each network layer for a metropolitan area optical fibers network. Generally, the quantity selection may correspond to the selection of the geographical coverage for connecting various participants in the constructed network. Particularly, the backbone layer quantity selection may correspond to the selection of the number of ISP connections with the incumbent central exchanges in the specific area where the MAN will be constructed. In the transmission layer, the quantity may correspond to the number of local concentrators connected with optical fiber providing VDSL connections. Finally, regarding the access part of the network, the quantity may correspond to the number of customer premises connected with optical fibers.

Especially for the dark fiber network where the overall demand is given, they may consider that when a player captures a part of the market demand the rest of it is still available for its competitor. This is realistic for the broadband business field since after the first installation of the dark fiber and the physical connection of the various components of the network there is no reason for someone else to install similar physical connection. Duplication of passive infrastructure networks might be neither privately profitable nor socially desirable.

On the other hand, the service attribute (quality) may correspond to the provision of the bandwidth level, the quality-reliability of Internet connection or the quality of service support for failure connection problems. Also, the service attribute may concern double play or even more triple play mode. Finally, the service attribute may concern terminal equipment provided to the customers.

The aforementioned discussion is summarized schematically in Fig. 4.

Thus, the same type of competition is proposed for each business layer; however, different competition characteristics can be considered for each network layer.

2.2.2. Demand–cost–revenues estimation

Next, the proposed model is built and analyzed. All the notations used are given in Table A1 in Appendix A.

2.2.2.1. Stage s_{qc}: PassNet (Quantity competition). In the case of quantity competition each competing firm pays an investment infrastructure cost, $I_{s_{qc}}$, in order to enter into the market. Each firm, after receiving the additional information concerning the respective action of the competitor, decides how much to produce and offer in the specific market.

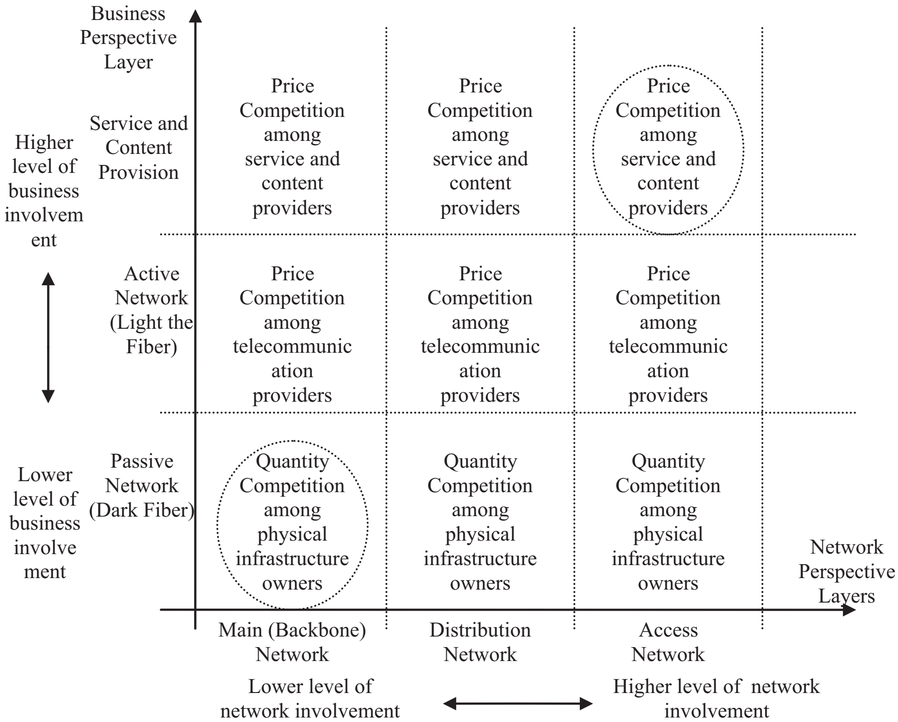

Fig. 4. The type of competition at various business and network layers.

For stage s_{qc}, it is assumed for simplicity that the price of the service (product) is a linear inverse demand function of the form (Smit & Trigeorgis, 2004):

$$p_{s_{qc}}(D_{s_{qc}},Q)=D_{s_{qc}}-b(q_{s_{qc}A}+q_{s_{qc}B}) \tag{1}$$

where $p_{s_{qc}}$ is the price of the service (product) and $D_{s_{qc}}$ is the demand parameter for stage s_{qc}. Parameter b measures the elasticity of the demand, while $Q(=q_{s_{qc}A}+q_{s_{qc}B})$ is the aggregate quantity on the market, where $q_{s_{qc}A}$ and $q_{s_{qc}B}$ are the quantities offered by firms A and B in stage s_{qc}.

The overall cost function of the stage s_{qc} for firm i is given by

$$C_{s_{qc}i}(q_{s_{qc}i})=c_{s_{qc}i}q_{s_{qc}i}+F_{s_{qc}i} \tag{2}$$

where $F_{s_{qc}i}$ is the fixed cost, and $c_{s_{qc}i}$ is the marginal cost of the provided product (service) for firm i.

Finally, the operational profit of firm i at stage s_{qc} is given by

$$P_{s_{qc}i}(q_{s_{qc}A},q_{s_{qc}B})=p_{s_{qc}}q_{s_{qc}i}-c_{s_{qc}i}q_{s_{qc}i} \tag{3}$$

The possible decisions for each player (firm) are invest (IN), defer investment (DF), and abandon (A). There are two possible decision modes: simultaneous (SIM) investments and sequential (SQ) investments. Particularly, if one firm invests and the other does not then they have monopoly (M) conditions. If both firms invest at t then they have SIM decisions. While if one invests in t and the other in $t+1$ period then they have SQ decisions indicating first mover (FM) and second mover (SM) modes. Finally, if none of them invests then they have no business at all for this stage. Angelou and Economides (2011, 2009b) and Zhu (1999) estimate the decision equilibrium for each investment mode. Particularly, they estimate the decision equilibrium according to the demand of the service (product) produced (Fig. 5).

The equilibriums to make investment and exercise the business option are defined by the market demand level that make investment profitable (i.e. NPV >0). Particularly, the Net Present Value (NPV) (Angelou & Economides, 2009b) is adopted

$$\text{NPV}_{s_{pc}i}=P_{s_{qc}i}-I_{s_{qc}i}>0 \tag{4}$$

Hence, the decisions strategies according to the demand level are the following:

(IN,IN) if $D_{s_{qc}}>c_{s_{qc}i}+3\sqrt{\text{br}\, I_{s_{qc}i}}=D_{s_{qc}SM}$, (DF,DF) if $D_{s_{qc}}\le c_{s_{qc}i}+2\sqrt{\text{br}\, I_{s_{qc}i}}=D_{s_{qc}M}$,

mixed strategy (IN,IN) or (DF,IN),

if $D_{s_{qc}FM}=c_{s_{qc}i}+2\sqrt{\text{br}\, I_{s_{qc}i}}<D_{s_{qc}}\le c_{s_{qc}i}+3\sqrt{\text{br}\, I_{s_{qc}i}}=D_{s_{qc}SIM}$

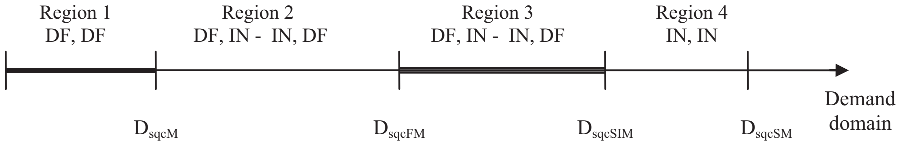

Fig. 5. Decisions equilibrium and demand zones analysis for investment strategy (Zhu, 1999).

2.2.2.2. Stage s_{pc}: ActNet, SerPro (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 quality of service support for failure connection problems. It is usual in the Greek broadband business field that the incumbent operator presents 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 terminal equipment to the customer premises. 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 $t_{s_{pc}}$ which is uniformly distributed over the interval $[l_{s_{pc}}, h_{s_{pc}}]$, where $h_{s_{pc}} > l_{s_{pc}} > 0$. Customers with $t_{s_{pc}} = h_{s_{pc}}$ have the highest interest in the service/product for stage s_{pc}. Customers with $t_{s_{pc}} = l_{s_{pc}}$ have the less interest in the service/product. The density of customers for stage s_{pc}, is $N_{s_{pc}}$ per unit of the type index. Hence, the total number of customers (overall market size) is $N_{s_{pc}}(h_{s_{pc}} - l_{s_{pc}})$.

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

$$U^{t_{s_{pc}}}_{customer}(t_{s_{pc}}, u_{s_{pc}x}, p_{s_{pc}i}) = V^{t_{s_{pc}}}(t_{s_{pc}}, u_{s_{pc}x}) - p_{s_{pc}i} \tag{5}$$

where

$$\frac{\partial V^{t_{s_{pc}}}}{\partial u_{s_{pc}x}} > 0, \quad \frac{\partial V^{t_{s_{pc}}}}{\partial t_{s_{pc}}} > 0$$

The following function for utility estimation is adopted (Zhu, 1999):

$$U^{t_{s_{pc}}}_{customer}(t_{s_{pc}}, u_{s_{pc}x}, p_{s_{pc}i}) = \omega u_{s_{pc}x} t_{s_{pc}} - p_{s_{pc}i} \tag{6}$$

The type $t_{s_{pc}}$ customer will buy the product if the utility value is positive

$$t_{s_{pc}} \geq \frac{p_{s_{pc}i}}{\omega u_{s_{pc}x}} = t_{s_{pc}0}$$

Since all customers in $[t_{s_{pc}0}, h_{s_{pc}}]$ have positive utility value and so will choose to buy the product, the total demand, $D_{s_{pc}i}$ is

$$D_{s_{pc}i} = N_{s_{pc}}(h_{s_{pc}} - p_{s_{pc}i}/\omega u_{s_{pc}x}) \tag{7}$$

They assume that the marginal cost of firm i for producing each product unit is $c_{s_{pc}i}$. The development cost is assumed to be $k_{s_{pc}} u^2_{s_{pc}x}$ (Angelou & Economides, 2009b), where the increase of service quality becomes even more difficult as the level of quality increases. Hence, the overall cost function is

$$C_{s_{pc}i} = k_{s_{pc}} u^2_{s_{pc}x} + c_{s_{pc}i} D_{s_{pc}i} \tag{8}$$

where $k_{s_{pc}}$ is the coefficient of the development cost for stage s_{pc}. 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 they assume that the marginal cost of $c_{s_{pc}i}$ equals zero since in practice when the infrastructure is built and fiber passes outside a home the cost of customers connection (mainly the activation of it) is very small. This assumption does not change the conclusions of their analysis. Finally, the operational profit is given by

$$P_{s_{pc}i} = p_{s_{pc}i} D_{s_{pc}i} - C_{s_{pc}i} \tag{9}$$

Angelou and Economides (2009b) estimate the equilibrium strategies of the firms. The equilibriums to make the investment and exercise the business option are defined by the market demand thresholds that make investment profitable. They also adopt positive NPV for stage s_{pc}

$$\mathrm{NPV}_{s_{pc}i} = P_{s_{pc}i} - I_{s_{pc}i} > 0 \tag{10}$$

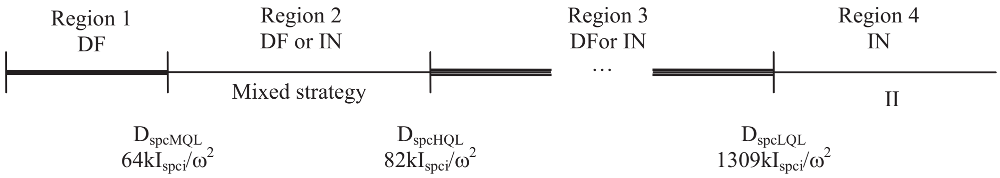

Fig. 6. Demand regions for one-period price competition game (Zhu, 1999).

$$\text{(IN,IN)} \quad \text{if} \;\; N_{s_{pc}}^2 h_{s_{pc}}^4 > 1309k\frac{I_{spci}}{\omega^2}, \quad \text{(DF,IN)} \quad \text{if} \;\; 82k\frac{I_{spci}}{\omega^2} < N_{s_{pc}}^2 h_{s_{pc}}^4 \leq 1309k\frac{I_{spci}}{\omega^2},$$

$$\text{(DF,DF)} \quad \text{if} \; N_{s_{pc}}^2 h_{s_{pc}}^4 \leq 64k\frac{I_{spci}}{\omega^2},$$

$$\text{mixed strategy (IN,DF)} \quad \text{or} \quad \text{(DF,IN)} \quad \text{if} \;\; 64k\frac{I_{spci}}{\omega^2} < N_{s_{pc}}^4 h_{s_{pc}}^4 \leq 82k\frac{I_{spci}}{\omega^2}$$

where $I_{s_{pc}i}$ is the investment (infrastructure) cost for firm i, in Fig. 6.

Angelou and Economides (2009b) estimate the business value according to the demand level. 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. Finally, Angelou and Economides (2011), for the broadband business field, show that the firm with the best quality attribute is able to charge higher prices and so experience higher revenues.

2.3. Estimation of the business utility at each stage

Angelou and Economides (2009b) and Zhu (1999) focus on a one-period game. They assume that business for each of the aforementioned stages is available for one period and estimate the equilibrium strategies of the firms. Also, Angelou and Economides (2011) analyze business equilibrium for the second and third stages of the business problem adopting price competition modeling in a compound ROs perspective. Here, the authors focus on the first two stages (s_{qc}: PassNet and s_{pc}: ActNet) adopting multiperiod analysis for the first s_{qc} stage.

For stage s_{qc} (PassNet), this study assumes 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. The firms invest simultaneously (SIM) or sequentially (SQ). In the second case, there are the first mover (FM) and second mover (SM) decisions. In the SIM investments, the firms make their decisions without observing each other, so each firm has imperfect information about its competitor's decisions. Particularly, it is the information structure, and not necessarily the timing, that defines the game. It is not necessary that firms make their decisions simultaneously but each firm chooses a strategy without knowledge of the competitor's choice (Zhu, 1999). After deciding to invest or defer and having observed the decision of their competitor, which are based on the expected level of the market demand, the firms are able to recognize the evolution of the market demand.

For the first period, there are FM_1, SM_1, SIM_1, M_1 decision cases. Afterwards, for the second period, there is the examination of the evolution of the market demand, and there are again FM_2, SM_2, SIM_2, M_2 decision cases to be analyzed (Fig. 7). This second period actually indicates the ROs perspective.

They consider a binomial process for customer demand ($D_{s_{pc}}$), where u_p and d_n are the changes up to $u_pD_{s_{pc}}$ or down to $d_nD_{s_{pc}}$ according to a binomial process (Fig. 8). Especially, u_p and d_n are the multiplicative binomial parameters ($u_p > 1$, $d_n < 1$).

They 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). Finally, when having these values for each period, both firms choose the equilibrium strategies. Angelou and Economides (2009b) discussed the equilibrium decisions according to demand level showing that that the equilibrium will be (DF, DF) if demand is below the value $D_{s_{qc}} < (1/d_n)(c_{s_{qc}i} + 3\sqrt{\text{br}\, I_{s_{qc}i}})$, and (IN, IN) if demand is above this level.

If the investment decision is IN in the first period, before analyzing the customers demand, 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 $t+1$ and then decide according to the market demand, the overall value is given by the Expanded NPV, which actually contains the ROV (Trigeorgis, 1996).

The ENPV for stage s_{qc} (PassNet) is given by

$$\text{ENPV}_{s_{qc}i} = \text{ROV}_{s_{qc}i} = \frac{1}{1+r}\left\{\begin{array}{l} q\max[u_pP_{s_{qc}i} - I_{s_{qc}i}, 0] \\ +(1-q)\max[d_nP_{s_{qc}i} - I_{s_{qc}i}, 0] \end{array}\right\} \tag{11}$$

In the risk-neutral valuation of ROs, q is defined as the risk-neutral probability (Trigeorgis, 1996).

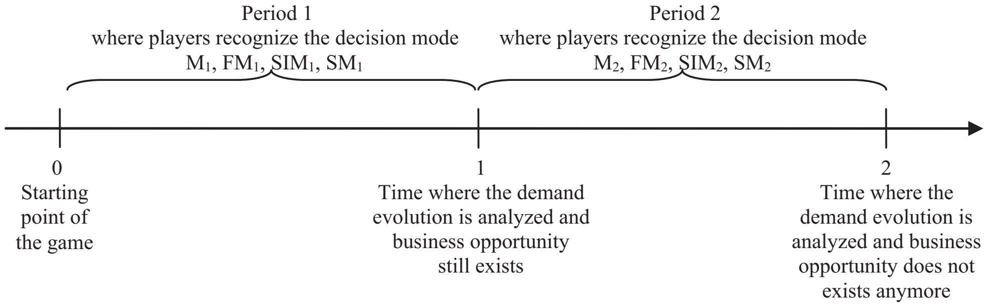

Fig. 7. The time sequence of the game's actions among players for stage s_{qc} (PassNet) business.

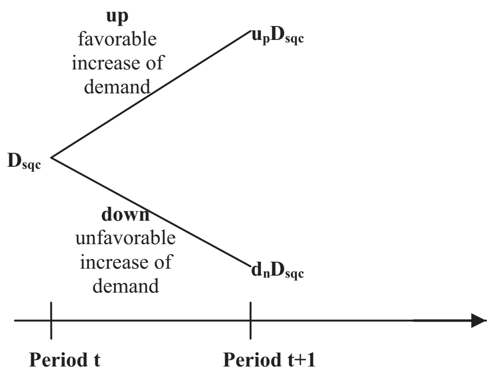

Fig. 8. Uncertain demand as binomial process.

2.4. Estimation of the overall business game

For the estimation of the overall multistage game equilibrium, they define the overall business utility (OBU) which includes all the pay offs for each business stage and is given by

$$\text{OBU} = \sum \text{ENPV}_1(+\text{ENPV}_2(+\text{ENPV}_{S-s}(\cdots(+\text{ENPV}_S)))) \tag{12}$$

where S is the total number of business stages. Particularly, for two stages (PassNet, ActNet) business analysis, the OBU is given by

$$\text{OBU}_i = \text{ENPV}_{PassNet}(\text{ENPV}_{ActNet}) \tag{13}$$

Adopting compound ROs analysis, for the s_{qc} (PassNet) stage that contains the s_{pc} (ActNet) stage, the overall ENPV based on the compound options analysis is given by

$$\text{OBU}_i = \text{ROV}_{PassNeti} = \frac{1}{1+r}\left\{\begin{array}{l} q\max[u_p P_{PassNeti} - I_{PassNeti} + \text{ROV}_{ActNeti}, 0] \\ +(1-q)\max[d_n P_{PassNeti} - I_{PassNeti} + \text{ROV}_{ActNeti}, 0] \end{array}\right\} \tag{14}$$

The ENPV for stage s_{pc} (ActNet) is given by the following:

$$\text{ENPV}_{ActNet} = \text{ROV}_{ActNet} = \frac{1}{1+r}\left\{\begin{array}{l} q\max[uP_{ActNet} - I_{ActNet}, 0] \\ +(1-q)\max[dP_{ActNet} - I_{ActNet}, 0] \end{array}\right\} \tag{15}$$

In the simplest case, the overall business utility is given by the sum of each business stage profit

$$\text{OBU} = \text{ENPV}_{PassNet} + \text{ENPV}_{ActNet} \tag{16}$$

As discussed the game equilibrium for each stage of the business game depends on the customers' demand.

Fig. 9 presents the combined case of quantity and price competition and the two dimensions of customers demand domains for both types of competition. Analytically, the level of the customers' demand defines the equilibrium strategies among the firms (competitors). In case of asymmetries among the firms (e.g. cost asymmetry), the demand thresholds will be different for each firm indicating different investment decision according to the aforementioned analysis.

Fig. 9 presents in two dimensions the demand thresholds for both stages. The horizontal axis presents the demand threshold for stage PassNet (quantity competition) and the vertical axis presents the demand threshold for stage ActNet (price competition). The overall business equilibrium should be the combination of the two dimensions. Particularly, the

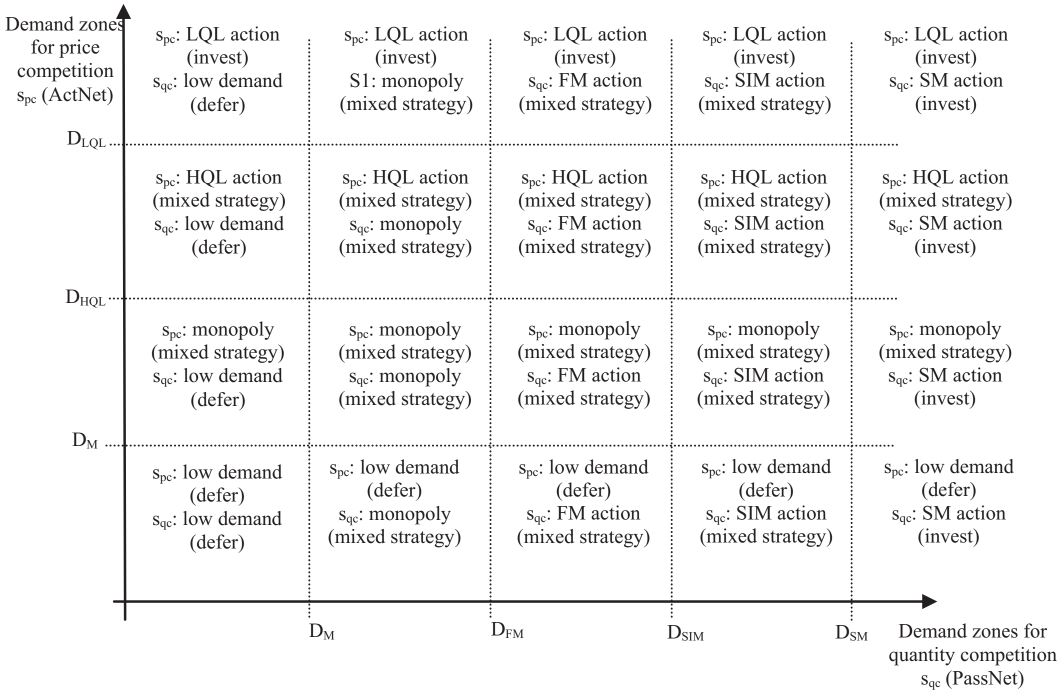

Fig. 9. Demand thresholds for decisions alternatives and type of competition.

demand level for each business stage is recognized indicating so the optimal investment decision. The combination of the two axis conclude to the overall decision equilibrium.

2.5. Comparison between utility companies and telecommunication operators

Next a SWOT analysis is provided to evaluate the Strengths, Weaknesses, Opportunities, and Threats for utility companies. SWOT analysis groups key information into two main categories:

- *Internal factors*—The strengths and weaknesses internal to the organization.
- *External factors*—The opportunities and threats presented by the external environment to the organization.

The internal factors may be viewed as strengths or weaknesses depending upon their impact on the organization's objectives. The external factors may include macroeconomic matters, technological change, legislation, and socio-cultural changes, as well as changes in the marketplace or competitive position. The results are often presented in the form of a matrix.

Fig. 10 presents the SWOT analysis for utility companies, considering broadband business activity indicating so the differences with the telecommunication operators.

Basic characteristics for telecommunication operators are the following:

- knowledge of telecommunication business,
- existing infrastructure,
- established customers base,
- services offered.

On the other hand, utility companies experience the following:

- existing infrastructure which can be reused, for example, sewage systems,
- cost efficient network rollout,
- no experience with telecommunications, not a service provider,
- lack of knowledge regarding telecommunications.

Strengths	Weaknesses
• Large scale utility infrastructure in the area with possible space for installing network equipment. • Large customer base and service points. • Lower implementation cost due to reuse of existing infrastructure (e.g. sewage pipes for optical fibers installation). • First to be informed of new building developments – even before telecommunication operators. • Strong Trusted brand.	• No defined company structure yet (roles, responsibilities and processes & departments). • Lack of broad telecommunications business experience. • Organization not yet ready for new business. • ISPs, Incumbent or competitors plan to deploy their own fiber networks.
Opportunities	**Threats**
• International Strategic Partnerships. • Deploy large capacity networks in shortest time frame with lower cost. • Exploit high broadband business growth.	• Lack of infrastructure Network Security. • Service Providers building fiber networks. • National incumbent's market power • Delay in implementation investment program (leading to Service Providers building fiber networks). • Legal/regulatory issues.

Fig. 10. SWOT matrix for utility companies.

3. A case study

To illustrate the proposed methodology they apply it to an ICT investment decision for a growing Water Supply & Sewerage Company, which they refer to as WSSC to protect its identity and its projects. WSSC is interested in entering in the broadband business field and exploiting its physical infrastructure (water and sewerage pipes). The company examines the possibility of being involved in telecommunications business as a wholesale infrastructure provider and in parallel developing retail fiber access-based telecommunications services. WSSC may undertake the following roles:

- *PassNet*: it builds and owns the telecommunications access infrastructure which includes passive connection—supply and installs ducts, conduits and 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.

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. Although the cost of broadband infrastructures has decreased, the required investments remain an obstacle for the private sector (Angelou & Economides, 2009b). 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 of growth (Angelou & Economides, 2011). In particular, Greece has a fixed broadband penetration rate of about 20% and a total Internet penetration rate of about 50% (Internet in Greece).

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).

Bouras et al. (2009) propose a business model for the optimal exploitation of the currently developing broadband metropolitan area networks in Greece. Having recorded and examined relevant international practices, they describe in detail the way that these networks should be managed, operated, maintained and expanded.

Finally, Troulos and Maglaris (2011) provide a holistic view of municipal broadband in Europe, aiming to understand the factors that determine municipal strategies in fixed Next-Generation Access (NGA) networks and the implications of municipal broadband to regulation and markets. In order to do that they review 74 municipal broadband use cases across 10 European countries.

Angelou and Economides (2011) provide an Internet survey for the current broadband business situation in Greece. In addition to the incumbent operator OTE there are 7 broadband service providers offering mainly services in large Greek cities. Broadband services providers offer up to 24 Mb/s downlink and 1 Mb/s uplink.

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 (Tsinaris, 2008). Similar broadband metropolitan networks have been developed all over the world (Stadtwerke

Case Study—FTTx 2nd European Next Generation Access Network Forum, n.d.; TransACT, 2012; Fälth, 2012). Indicatively, they mention Sweden (Stockholm, Helsinborg), Austria (Vienna), Spain (Catalonia), New Zealand (the city of Wellington), Netherlands (Amsterdam), USA (a group of cities in Utah) , Australia (Canberra). 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 interested reader is referred to Bouras (2008b), FTTX News (2009), Point-topic (2011) and Observatory For Penetration in Greece (2012).

3.1. The specific market conditions for WSSC

The overall competition of the WSSC in the broadband business plans to deploy its own fiber network. Hence, WSSC with its subsidiary NewTelco Services considers 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.

According to regulation which demands for open access networks, the new network should be promoted as an open access network. Also, local authorities have a time consuming licensing processes. It is difficult to obtain permission for installation (digging, etc.) of fiber optics.

All these problems, which also apply to the region of interest for WSSC, give an advantage to the authorities that have the capability to overcome these, or have already installed fiber cables, for the next 5 years. WSSC may gain a step forwards since it does not need to acquire a permission for digging since the optical fiber can be installed through its sewerage pipes. This gives a significant competitive advantage to the WSSC against its possible competitors since civil works is the major cost of the overall initial, sunk cost (Fig. 11).

However, WSSC does not have enough experience for such type of business activities, while the new subsidiary will require some time to be activated and efficiently organized. So, a delay for clarifying some organizational issues in the new subsidiary could be considered. Thus, from the WSSC's perspective a decision to enter into the broadband business can be a matter of timing. It is examined whether WSSC can afford to wait or should move really rapidly sacrificing uncertainties clearness in order not to lose its competitive advantage and even more the overall business value. 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 common 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 WSSC 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.

The overall market includes 100,000 potential business and domestic customers. For the first stage, 100 km dark fiber will be installed for connecting incumbent operator local switching centers, to implement the backbone network. Along that way there are 400 customers premises/km. So, the overall market size is 40,000 customer premises for FTTH connection. Assuming a penetration of 25%, the overall customers demand is 10,000 FTTx connections. The infrastructure cost I_{1i} includes ducts and dark fiber installation along the streets in the area of interest.

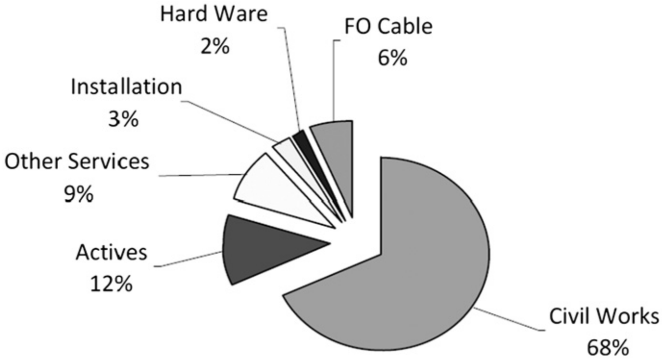

Fig. 11. Costs in percentage during the first year of the installation of a new optical fiber network (Bouras, 2008a).

Table 2
Pay offs for stage 1 (PassNet) and 2 (ActNet) strategies for each firm.

Strategy		Pay off (*1,000,000€)		
Stage 1	**Stage 2**	**Stage 1**	**Stage 2**	**Overall**
IN_M	IN_{MQL}	181.2	16.8	198
IN_M	DF(A)	181.2	0	181.2
IN_{FM}	IN_{HQL}	86.6	13	99.6
IN_{FM}	IN_{LQL}	86.6	0.25	86.85
IN_{FM}	DF(A)	86.6	0	86.6
IN_{SIM}	IN_{HQL}	76.1	13	89.1
IN_{SIM}	IN_{LQL}	76.1	0.25	76.35
IN_{SIM}	DF(A)	76.1	0	76.1
IN_{SM}	IN_{HQL}	39.3	13	52.3
IN_{SM}	IN_{LQL}	39.3	0.25	39.55
IN_{SM}	DF(A)	39.3	0	39.3
DF_M	IN_{MQL}	186.7	16.8	203.5
DF_M	DF(A)	186.7	0	186.7
DF_{FM}	IN_{HQL}	90.3	13	103.3
DF_{FM}	IN_{LQL}	90.3	0.25	90.55
DF_{FM}	DF(A)	90.3	0	90.3
DF_{SIM}	IN_{HQL}	79.6	13	92.6
DF_{SIM}	IN_{LQL}	79.6	0.25	79.85
DF_{SIM}	DF(A)	79.6	0	79.6
DF_{SM}	IN_{HQL}	42.1	13	55.1
DF_{SM}	IN_{LQL}	42.1	0.25	42.35
DF_{SM}	DF(A)	42.1	0	42.1
A	–	0	0	0

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

The NPVs and ENPVs for the case study are presented in Table 2. Also, the demand thresholds for the various decisions modes are estimated. For stage PassNet, the resulting equilibrium, under symmetrical firms, will be SIM decisions since FM action is more profitable and both firms will choose it. For stage ActNet, the firm with the higher quality of the broadband bandwidth provision will achieve higher profits.

Especially, for WSSC and stage ActNet business, high quality could mean:

- provision of real FTTH connection and not VDSL connection (the competitor in this case is the incumbent operator, and has its 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, while for its competition this is a difficult task, provides the option to be the higher quality firm in the area of interest. Particularly, WSSC should exploit its advantage for real FFTH connection. This advantage is known to its competitors that normally should plan for the most conventional VDSL connections.

In addition, the evaluation of the demand thresholds is presented in Table 3, for the various values of the initial infrastructure cost I_{1i} as well as the marginal cost of implementing the final connection from the street where the dark fiber is running up to customers' premises. These thresholds define the demand levels, for each decision combination of the two firms, where the business value is positive.

As seen, the infrastructure cost is more critical than the marginal cost or street to customer cost. Particularly, similar change of infrastructure and marginal costs cause higher change of the demand thresholds for the infrastructure than the marginal cost.

Especially, for the WSSC case, where WSSC experiences significant cost advantage against its competition, the demand threshold for making profitable investments is much lower than its competitions. This fact actually indicates the FM attributes, which WSSC is experiencing.

In conclusion, for stage one, cost asymmetry among WSSC and its competition and capability of offering higher quality bandwidth should activate a FM strategy for WSSC either in the first period or in the second period of analysis.

Hence, in the first stage (the overall business initialization and DF installation), WSSC should act as FM against its competition. In the second stage, it is more profitable for WSSC to offer higher level of bandwidth, being able to charge it with higher price than its competition.

Table 3
Sensitivity analysis of demand thresholds with respect to infrastructure and marginal cost.

Sensitivity analysis for the stage 1 infrastructure cost					
I_{1i}	12,000,000€	10,000,000€	**8,000,000**€	6,000,000€	4,000,000€
D_{1iM}	2.593	2.376	2.136	1.863	1.539
D_{1iSIM}	3.840	3.514	3.154	2.744	2.259
D_{1iFM}	3.626	3.319	2.979	2.593	2.136
D_{1iSM}	5.086	4.652	4.171	3.626	2.979
Sensitivity analysis for the stage 1 marginal cost					
c_{1i}	225€	150€	**100**€	50€	25€
D_{1iM}	2.261	2.186	2.136	2.086	2.061
D_{1iSIM}	3.279	3.204	3.154	3.104	3.079
D_{1iFM}	3.104	3.029	2.979	2.929	2.904
D_{1iSM}	4.296	4.221	4.171	4.121	4.096

4. Discussion and future research

There is empirical evidence to support the fact that managers who are aware of some options-like ideas do a better job of evaluating and optimally deploy business (Kumar, 2002). Also, senior finance executives are becoming increasingly aware of the need to view infrastructure investments and growth opportunities based on this infrastructure as ROs. ROs have already applied in the literature for evaluation of ICT and more particularly broadband investments.

In practice, managers may identify stages of overall business, and identify options mapped to 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. Particularly, the issue becomes even more complicated in ICT markets. Particularly, after the ICT markets deregulation, competition intensity has been increased dramatically and the players in the ICT investment field should model competition threat that influences their business potential.

Hence, the quantitative analysis of competition influence in broadband investment opportunities, treated as ROs, is a very challenging task that requires the integration of GT with the ROs.

Analytically, this paper proposes a framework for broadband business analysis taking into account broadband business developed in stages, which 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 adds in the modeling dimension beyond that by introducing a compound competition perspective.

The primary contribution of this paper is the provided solid evidence that the broadband business treated in stages, with different 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. However, competition presence causes decision makers to rush equilibrium, adopting smaller deferring period.

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 managerial implications of their 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 means 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 deffering investment. This philosophy proposes the waiting strategy instead of acting immediately if expected customers demand is below a specific threshold.

Acting as FM may be more profitable, and especially under symmetric conditions this will lead to SIM decisions and early exercise of the option. However, under asymmetric players (e.g. different infrastructure and marginal costs), the FM strategy is in the hands of the firm that faces the competitive advantage.

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. Also, the deferring period may be composed by many periods. In this case, the competitors collect specific business information, analyze it and run the model for selecting the most suitable strategy for them, taking also into account their competitors decisions.

ROs have been already applied in the literature for evaluating ICT investments. However, the option analysis experiences criticism concerning the need for the parameters' quantification of the ROs models. The issue becomes even more complicated in the ICT markets. An extension of their work can include multi-criteria taking into account both quantitative and qualitative factors based on the analysis of Angelou and Economides (2009a) work. Particularly, they integrate ROs and GT in one utility function adopting the Analytic Hierarchy Process technique.

Also, it is assumed that each business stage is independent from the following ones. Someone may relax this assumption and consider inter-dependencies among the various business stages. Finally, adopting multi-competitors equilibrium estimation will be definitely more realistic and closer to the real business conditions in the telecommunications field.

5. Conclusion

This paper examines business activities for municipalities and utility companies in the broadband business field. It models competition and provides an overall analysis for the whole business, which can be divided in stages. It adopts different competition type for each stage and discusses the equilibrium quantities and revenues considering a two-player business game. Also, a real business case is analyzed by using the proposed framework. The results of the analysis prove that delay of investment may be more attractive under business uncertainty even if there are monopolistic conditions in the market. Finally, it discusses limitations of the proposed analysis and provides suggestions for future research.

Appendix A

The notations used in the analysis are given in Table A1.

Table A1
Notations used in their model.

Notation	*Definition*	*Values of the parameters in the case study*
s_{qc}	Index of the available business stages with quantity competition (s_{qc}: PassNet)	PassNet
s_{pc}	Index of the available business stages with price competition (s_{pc}: ActNet, SerPro)	ActNet
S	Overall number of business stages S	Two stages considered in the analysis as well as the case study
$D_{s_{qc}}$	Customers total demand for business stage s_{qc}	10,000 FTTx dark fiber connections
$d_n D_{s_{qc}}$	Decrease of demand moving down by d_n (binominal process) at time period $t+1$	$d_n = 0.74$
$u_p D_{s_{qc}}$	Increase of demand moving up by u_p (binominal process) at time period $t+1$	$u_p = 1.35$
q	Risk neutral probability	0.51
$p_{s_{qc}}$	Price of service (product) offered for stage s_{qc}	
$q_{s_{qc}i}$	Quantities offered by firm $i = A$, B in stage s_{qc}	
Q	$Q = q_{s_{qc}A} + q_{s_{qc}B}$ is the overall quantity offered on the market for stage s_{qc} by both firms	
b	It measures the elasticity of demand for stage s_{qc}	
$c_{s_{qc}i}$	Marginal cost of service/product offer for stage s_{qc} for firm i	100 €
$C_{s_{qc}i}$	The overall operational cost function for stage s_{qc} for firm i	
$F_{s_{qc}i}$	Fixed cost for stage s_{qc} for firm i	
$I_{s_{qc}i}$	Business infrastructure cost (one-time cost) for stage s_{qc}. It is the cost of connecting with dark fiber the main, distribution and access nodes (not the last mile implementation)	8,000,000€. It corresponds to the cost of installing dark fiber along the street up to the access cabinet in a neighborhood level
r	Discount factor (the same discount factor is assumed for both stages)	5% (It assumes 10 years of business operation period)
$P_{s_{qc}i}$	Business operational profit for stage s_{qc} for competitor $i = A$, B	
$D_{s_{qc}M}$	Customers demand threshold for monopoly case for stage s_{qc}	
$D_{s_{qc}FM}$	Customers demand threshold for first mover case for stage s_{qc}	
$D_{s_{qc}SIM}$	Customers demand threshold for simultaneous movement case for stage s_{qc}	
$D_{s_{qc}SM}$	Customers demand threshold for second mover case for stage s_{qc}	
$NPV_{s_{qc}i}$	Net Present Value of business opportunity for stage s_{qc} and firm i	
$ENPV_{s_{qc}i}$		

Table A1 (*continued*)

Notation	Definition	Values of the parameters in the case study
	Expanded Net Present Value of business opportunity which contains the ROV for stage s_{qc} and firm i	
$ROV_{s_{qc}i}$	Real option value (ROV) of business opportunity for stage s_{qc} and firm i	
$ENPV_{s_{pc}i}$	Expanded Net Present Value of business opportunity which contains the ROV for stage s_{pc} and firm i	
$ROV_{s_{pc}i}$	Real option value (ROV) of business opportunity for stage s_{pc} and firm i	
$D_{s_{pc}i}$	Customers total demand for business stage s_{pc}	6000 FFTH active fiber connections (3000 domestic connections, 3000 business-domestic connections)
$l_{s_{pc}}$	Lower index of customers type of the market being interest to buy service (product) with specific quality attributes for stage s_{pc}	
$h_{s_{pc}}$	Higher index of customers type of the market being interest to buy service (product) with specific quality attributes for stage s_{pc}	2 (it considers two types of customers: domestic customers, and business-domestic customers)
$N_{s_{pc}}$	Number of customers for each customer type for stage s_{pc}	3000
$D_{s_{pc}MQL}$	Customers demand threshold for monopoly quality case for stage s_{pc}	
$D_{s_{pc}HQL}$	Customers demand threshold for high quality case for stage s_{pc}	
$D_{s_{pc}LQL}$	Customers demand threshold for low quality case for stage s_{pc}	
$C_{s_{pc}i}$	The overall operational cost function for stage s_{pc} for firm $i=A$, B	
$F_{s_{pc}i}$	Fixed cost for stage s_{pc} for firm $i=A$, B	
$k_{s_{pc}}$	The coefficient of the development cost for stage s_{pc}	1
$c_{s_{pc}i}$	Marginal cost of service/product offer for stage s_{pc} for firm $i=1, 2$	0
$I_{s_{pc}i}$	Business infrastructure cost (one-time cost) at the time period t for stage s_{pc}. It is the cost of installing active equipment at the main, distribution and access nodes (not the last mile implementation)	
$t_{s_{pc}}$	Type of customers for stage s_{pc}	
$p_{s_{pc}i}$	Price of product/service offered for stage 2 for firm i	
$P_{s_{pc}i}$	Business operational profit for stage 2 for firm i	
$u_{s_{pc}x}$	Service quality charged with $p_{s_{pc}}$ for firm i (where $x=1,2,\ldots$, is quality index), $u_{s_{pc}2} > u_{s_{pc}1}$	
ω	Coefficient factor that is related the service (product) value for the customer	
OBU_i	Customers' overall business utility for firm i	

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