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ICT GROWTH OPTIONS ANALYSIS UNDER EXOGENOUS COMPETITION MODELING

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Abstract: In this paper, we estimate the value of an Information Communication Technology (ICT) investment opportunity, modeled as a Real Option (RO), when there is competition threat that can influence negatively its value or even more eliminate it. So far in the ICT literature, competition modeling is mainly focusing on duopoly market conditions, where investment actions taken by the firm may likely result in strategic answers by its competitors. However, after the ICT liberalization the number of firms has been increased, and the market structure tends to change from oligopoly to perfect competition. So, it is not practical to employ endogenous competition modeling. We relax the existing literature assumptions concerning exogenous competition modeling by considering that the competitors' arrival rate and the competitive erosion during the waiting and operating phase for the RO to invest follow stochastic processes in discrete time domain. We provide a ROs model, which estimates the value of a future investment opportunity when competitive entry can take part of the overall market value away from the firm that possesses this option. The results of our model prove that longer "wait-and-see" periods before exercising the ICT real option may indicate higher options values compared to the shorter ones, for some specific business conditions despite the competition threat for possible elimination of the future investment opportunity.

1. Introduction

Information and Communication Technologies (ICT) lie at the convergence of Information Technology, Telecommunications and Data Networking Technologies. The valuation of ICT investments is a challenging task because it is characterized by high level uncertainty and rapidly changing business conditions. Traditional finance theory suggests that firms should use a Discounted Cash Flow (DCF) methodology to analyze capital allocation requests. However, this approach does not properly account the flexibility inherent in most ICT investment decisions. ROs analysis presents an alternative method since it takes into account the managerial flexibility of responding to a change or new situation in business conditions [15]. An option gives its holder the right, but not the obligation, to buy (call option) or sell (put option) an underlying asset in the future. Financial options are options on financial assets (e.g. an option to buy 100 shares of Nokia at 90€ per share on January 2007). Real Option (RO) is the extension of the options concept to real assets. For example, an ICT investment can be viewed as an option to exchange the cost of the specific investment for the benefits resulting from this investment. By adopting the philosophy of managerial flexibility (also called active management) we decrease the possibility of experiencing losses while increase the possibility of gaining. This is achieved by waiting and learning about the changing business conditions and generally resolving over time part of the overall investment's uncertainty [3]. For a general overview of real options, Trigeorgis [15] provides an in-depth review and examples on different real options. For more practical issues the reader is referred to Mun [13]. Also, Angelou & Economides [2] apply ROs in a real life ICT case study. Finally, Angelou & Economides [1] provide a literature review of the ROs applications to real life ICT investments analysis.

After the liberalization of the telecommunications markets their market structure has changed from monopoly to oligopoly or perfect competition where many market participants are present. The real life ICT business activities do not belong exclusively to only one firm but may also be shared by other competitors. Viewing ICT projects as ROs, this paper develops a methodology for evaluating ICT investments decisions in the joint presence of uncertainty and competition. We adopt financial option theory and enhance it with competition modeling theory to guide decision-making regarding the management and evaluation of ICT investments. Our target is to develop a RO model closely related to the ICT industry characteristics to support ICT evaluation under competition conditions. As the number of players is increasing the exogenous competition modeling should take place since market conditions converge to perfect competition. In this case, a competitor's entry into the market will only cause a degradation of the overall ICT investment opportunity "pie", while the rest of the competitors will not react to this entry by changing their business strategy. On the other hand, in oligopolistic markets, actions taken by the firm may result in strategic reactions by its competitors. In this case, competition should be modeled endogenously requiring the combination of ROs and Game Theory [17].

Previous research has applied exogenous competition modeling to the shared investment opportunities where the anticipated competitive loss can be viewed as the impact of dividends on a call option [7],[11],[12],[15]. Examples include the opportunity to introduce a new product, which is influenced by the introduction of close substitutes or to penetrate a new geographic market without barriers to competitive entry.

In case of exogenous competition modeling the firm has to weight the value of waiting against the possible erosion of value of competitor's actions, which it cannot influence. The firm has to determine what information has available about competition. If for example the firm knows in advance the strategies of its competitors and their impact on the firm's value function, the situation is completely deterministic. However, this case is quite unrealistic. In reality, competitors are entering randomly the market and exercise their ROs. The firm might have a rough idea about the intensity of competition and its impact without having full information about when and how other firms act. Trigeorgis [16],[15] and Kumar [12] model competition exogenously assuming that the competitors are entering into the market following Poisson distribution. They assume that the underlying asset (investment value V) under random competitive arrivals can be modeled as a mixed diffusion-jump process.

We also consider that the competitors are entering the market randomly according to an exogenous Poisson distribution. We relax existing literature assumptions by considering that: i) the impact of each competitor's arrival, during waiting period is following a joint diffusion process with V, and ii) during operation period competitors may also enter the market and the impact of each arrival is also following a joint diffusion process with V. So far in the ROs literature, the impact of each competitor's arrival during the waiting period is assumed to be constant [12]. In addition, we consider that the expected arrival rate of competitors during operation period also follows a joint diffusion process with V and the impact of each arrival rate into the market.

It is also the first time where competition impact is modeled during the operation phase. Here, we focus on the Incumbent Operators (IO) site, which is facing a threat from other competitors. We model this threat and try to estimate its impact to the value of an investment that can be treated as RO to invest, in the near future, if the business conditions become favorable.

A good example of many players in an ICT market, which is dominated by a strong player, is the Greek telecommunication market, which is dominated by the incumbent fixed telephony operator OTE (Hellenic Telecommunications Organization) [9],[10]. After liberalization of the Greek market in 2001, an increasing number of new players has entered the market and started competing with the incumbent OTE in the value-added services. However, none of them pose a significant threat to OTE. Actually, there are about 12 more players who possess low market shares compared to OTE. However, each of them may subtract some value from the overall business value of any new investment opportunity from OTE if the latter remains "inactive". For any new value added service, there is a market "pie" concerning its business activity that is usually growing over time. Some parts, of the whole "pie" will be subtracted by the competitors as they are entering in the market. So, the IO here faces a tradeoff between the value of flexibility to wait and the value of the possible competitive erosion during waiting period. The OTE's management has to determine whether it should exercise the option and implement the investment opportunity early or whether it should follow "wait-and-see" (WaS) strategy despite a competitive damage caused by the competitors' entry in the market.

The rest of the paper is organized as follows. In Section 2, we provide a ROs model under exogenous competition modeling. In Section 3, we specify our analysis in the ICT market mapping its characteristics to the competition parameters of our model. We also put our analysis in the context of a specific illustration. Finally, in Section 4, we conclude and suggest possible future research.

2. A RO Model Under Competition Threat

We define T as the maximum deferral or "Wait-and-See" (WaS) period of the real option. During this period the option is shared among competitors. We assume that after this period no option exists at all for any competitor. The maximum deferral period is separated in two sub-periods, as seen in Figure 1. In the first sub-period, the IO is not investing and is waiting for resolving some of the uncertainties associated with this investment opportunity. The second sub-period starts when the IO exercises its option. For simplicity, we assume that the investment period (construction period for the specific project) is zero. The WaS period starts at t_s (assume t_s=0) when the option is available to the IO. Also, t_e is the real exercise time of the option (implementation of the investment opportunity). Finally, the part of the operation period where the IO can still face Competition Threat (CT) is T-t_e. All the notations used in our model are given in Table 1 in Appendix B. In addition, we define two terms for modeling the competition conditions: i) *Preemption Threat from Competitors* (PTC) and ii) *Preemption Capability of Incumbent* (PCI). PTC indicates the threat, which is experienced by the IO during the WaS period of the option that other competitors may enter into the market and decrease or even more eliminate the option value. PCI indicates the capability of the incumbent to preempt the subsequent competitors after its entry time at t= t_e into the market.

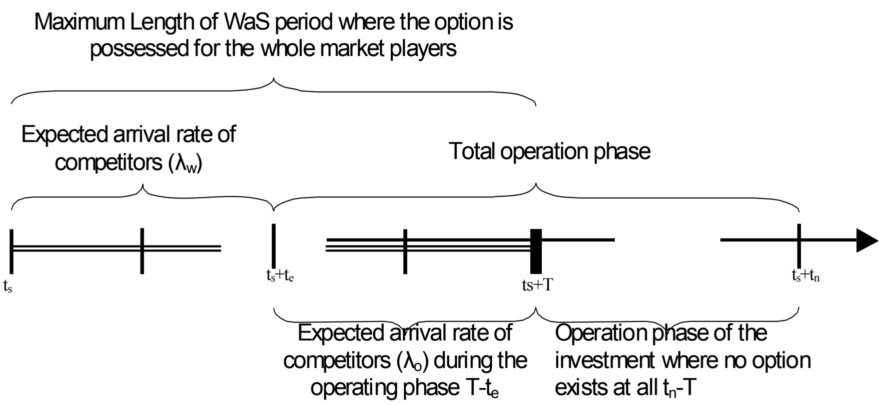

Fig. 1. Waiting and operation period for a single real option (t_s=0)

During the WaS period, competitors may enter the market causing degradation of the investment opportunity for the IO. We want to estimate the option value when there is a PTC against the IO. We model the PTC assuming that the competitors' arrival follows a Poisson distribution with an expected arrival rate λ_w and an expected competitive erosion c_w. The competitive erosion indicates the decrease of the investment revenues that are available to the IO, caused by each competitor's entry into the market.

The business target of the IO is to minimize the threat from competition that can significantly decrease or even more eliminate the option value and exercise its option at the optimum time compensating PTC and uncertainty control.

After the implementation of the investment (option exercise) the IO may also experience PTC up to time T that can further decrease its expected value of the operation's revenues. The target of the IO is to preempt the subsequent competitors, after this time. However, in case of hard competition, as it is in the ICT field where many competitors are sharing the same option, this is not realistic. Alternatively, the IO wants to minimize the effect of competitors' arrivals during the operation phase. Hence, an important characteristic for each business opportunity is to provide a strong capability for the IO to preempt subsequent competitors' entry after its entry in the market. At exercise time t_e, let I_{cwte} be the total competitive erosion of competitors who have already enter into the market. Let also V be the overall market investment revenues when no competition exists at all. Then, the revenues of the investment opportunity which are available to the incumbent are V - I_{cwte}. This value is fully available to the IO when there is full PCI to the following competitors, so no any competitor arrival is expected during the operation phase. However, as mentioned before, it seems more realistic to consider that a number of subsequent competitors can also enter the market after IO's entry into the market. We model a partial PIC by considering that during operation phase and up to t=T, competitors may also arrive with an expected competitors' arrival rate λ_o. The smaller the arrival rate λ_o is the higher the PCI is. Each of the arrivals during this period will cause a percentage decrease of the investment revenues defined as c_o. Hence, the final investment value that will be available to the incumbent is given by:

$$V_f = V - I_{cwte} - I_{co} \qquad (1)$$

where I_{co} is the total competitive erosion during the operation phase. Here, for simplicity we assume that competitive erosion during the WaS period is the same for any competitor's entry. The same applies for the operation period. We could easily extent our analysis to consider different competition effect for each competitor's entry into the market. However, the multi-diffusion analysis would become very complicated. Alternatively, we might consider that competition effects may follow the same diffusion process having different amplitudes.

The competitive erosion of the investment value, for the incumbent, during the waiting period is given by:

$$I_{cwt_e} = V - g_w^{n_w} V \qquad (2)$$

for n_w=0,1,2,... competitors entry during the waiting period

and the competitive erosion during the operation period is given by:

$$I_{co} = g_w^{n_w} V - g_o^{n_o} g_w^{n_w} V \qquad (3)$$

for n_o=0,1,2,.. competitors entry during the operation period.

Hence, assuming n_w competitors' arrivals during the waiting phase and n_o competitors' arrivals during the operation phase, the overall option value when it is exercised at $t=t_e$ is given by:

$$OV_{cte} = \max\left(V_f - X, 0\right) = \\ = \max\left[V\left[\sum_{n_w=0}^{\infty} P_{nw}\left(1-c_w\right)^{n_w}\right]\left[\sum_{n_o=0}^{\infty} P_{no}\left(1-c_o\right)^{n_o}\right] - X, 0\right] \quad (4)$$

where

$$P_{n_w} = P_{(c=n_w)} = \frac{e^{-\lambda_w(t_e-t_s)}\left(\lambda\left(t_e - t_s\right)\right)^{n_w}}{n_w!} \quad (5)$$

$$P_{no} = P_{(c=n_o)} = \frac{e^{-\lambda_o(t_s+T-t_e)}\left(\lambda_0\left(t_s + T - t_e\right)\right)^{n_o}}{n_o!} \quad (6)$$

are the probabilities of having specific number of competitors' arrivals, during the WaS and operation periods. In particular, P_{nw} indicates the probability of n_w competitors are arriving during the WaS period, while P_{no} indicates the probability of n_o competitors are arriving during the operation phase. As seen, the value of shared ROs with random competitive arrivals is a weighted sum or an expected value over a Poisson distribution. We do not consider any competitive "divided payout" as Trigeorgis [15] (pp. 287). Instead we consider the overall competition threat, which we treat as "competition cost" denoted as I_c. The magnitude of I_c depends on the competitive intensity, λ_w and λ_o, the market structure parameter c_w and c_o and the number of players n_w and n_o, which are finally entering the market.

PCI cases

No any PCI - We assume that I_{cwT}-I_{cwte}= $I_{co.}$ So, the IO has not any preemption capability. This results to wait up to t=T. It is more preferable to wait up to time T, since V_f will be the same independently of the option exercise strategy. Hence, it is the same as a proprietary option with revenues V_f and waiting period T. There is no reason to exercise this option earlier since longer waiting period indicates more efficient control of the uncertainties and higher option value [14]. In this case, we want to estimate the impact of the PTC, during the WaS period, to the option value of the IO.

Full PCI -We assume that I_{cwT}-I_{cwte}=I_{co}=0 for t_e<T. So, the IO has full preemption capability and exercises its options at $t=t_e$. In this case, we want to estimate, for the IO, the optimum time to invest (exercise its option). There are two effects negatively correlated between each other: i) the uncertainty control assured by both the ROs analysis and the managerial flexibility to deploy investment in a longer deferral period, and ii) the PTC that may fully eliminate the option value for the IO.

Partial PCI - It seems more realistic in real life business conditions that the IO may have a partial preemption capability. Actually, by investing earlier a level of preemption capability can be achieved. It might be optimal for the IO to invest earlier in order to ensure the highest possible level of the investment's revenues. Of course, it is still a matter of compensation between managerial flexibility and CT as before.

Finally, incentive of investing earlier can also be applied when WaS strategy results to significant revenues losses from the operation phase that overcome the value of the uncertainty control provided by the ROs approach. A divided yield parameter may indicate these revenues losses [15]. Here, we assume that this divided yield is zero.

3. Analysis Process

Assumptions

We assume that the IO as well as the rest of the competitors posse a shared RO that can be exercised up to t=T. In another paper submitted for publication we examine the option value for the first two cases, no PCI and full PCI. In this work we extent that work by assuming that IO has partial PCI, while the other competitors have no preemption capability at all. We consider a joint diffusion process for the c_w, c_o, λ_o and V (Figure 2 in the Appendix A), while we assume that the expected competitors arrival rate λ_w during WaS period is constant. The results of our analysis show that sometimes the IO may be better to adopt longer WaS period despite of the PTC that may eliminate the option value. We adopt an extended log transformed binomial model (ELTBM) with 4-parameters that follow joint diffusion process [5]. For small number of steps or volatilities values of the stochastic parameters with respect to the r, the Binomial Method becomes unstable since the up and down probabilities of asset parameters can be negative. ELTBM does not present this disadvantage being so fully stable and efficient.

So far in the literature the competitive erosion has been considered as constant. However, in the ICT markets, especially after the telecommunication's market deregulation, competition intensity has been increased dramatically. Hence, random competitive erosion seems more realistic. Geske [6] examines the impact of stochastic divided yield focusing on the financial traded options field. He does not mention anything about competitive erosion in the ROs analysis but focuses on a stochastic divided pay out on yearly basis. He shows that option value increases or decreases depending on the correlation between divided yield and the investment revenues V. Actually, if the correlation is negative then the option value increases. We extend this work to the ICT field. Similarly to divided-yield pay out, we consider the competitive erosion effect to be stochastic analysing deeper its impact on the option's value of the future investment opportunity. When the competitive erosion is stochastic the option value is given again by the equation 4. We consider c_w, c_o, λ_o as cost parameters, which either can be "added" to the overall investment cost or to the decrease of V due to competition. In this sense competitive erosion can be considered as asset (a part of cost) of the future investment opportunity (real option).

Correlation between V and competition parameters

In the following we examine the correlation value between V and competition parameters. One of our research interests is to examine the mapping of these parameters into real life ICT business activities.

c_w, c_o are positively correlated with V - If business conditions are bad, market demand is low, business opportunity seems to be not favourable and the possible competitor's entry can only capture a small part of the overall business opportunity. Someone may assume that the bad business conditions compared to the favourable ones experience no network externalities effects. The opposite may be assumed in case of favourable business conditions. Also, the bad business conditions indicate no achievement of the critical mass for the customers demand indicating so a relatively small subtraction of the overall investment opportunity available to the IO.

c_w, c_o are negatively correlated with V - Such cases may occur when while the market value appears appealing, the competitors cannot extract significant option value (e.g. not adequate ICT infrastructure to support high customers demand, cost disadvantage of other competitors compared to incumbents case, other idiosyncratic issues). Particularly, when competitors do not have the adequate ICT infrastructure to fully utilize their own investment's opportunity benefits, an increase of the overall market value V might finally decrease the part of the market share that a specific competitor can

subtract from incumbent. Finally, there might be cases where competitive erosion c_w, c_o are uncorrelated with V.

Correlation between c_w and c_o -It is reasonable to consider that competitive erosion parameters are negative correlated between each other. In particular, the higher the value of c_w is the smaller the value of the c_o will be since during operation period the competitors may experience weakness to gain a significant amount of the overall market value.

Correlation between V and λ_w, λ_o - In general, it seems more realistic to consider that λ_w, λ_o are positively correlated with V. However, there might be cases where λ_w, λ_o are not fully correlated with V. Such examples can be when there is information asymmetry for the overall market level between IO and the rest of competitors. Also, when there is cost asymmetry between IO and other competitors, meaning that investment cost seems very high for the latter compared to the IO cost structure. A cost advantage may be indicated by the availability or not of an initial ICT infrastructure investment for some players, we here assume for the IO, which enhances the investment capability. This specific ICT infrastructure may be able to support future investment opportunities in a more efficient way. Finally, another example can be when the market value increases more for the IO than for the rest of the competitors. However, this means that the real option to invest is not fully shared between IO and the other competitors.

Correlation between λ_w and c_w -It is reasonable to consider that λ_w is positively correlated to c_w since the higher the competitive erosion is the higher the competitors' incentive to invest will be too.

Correlation between λ_o and c_o -It is also reasonable to consider that λ_o is positively correlated to c_o since the higher the competitive erosion is the higher the competitors' incentive to invest will be too.

Correlation between λ_w and λ_o -It is reasonable to consider that expected arrival rates of competitors during WaS and operation periods are negative correlated between each other. In particular, the higher the value of λ_w is the smaller the value of the λ_o will be since during operation period the competitors, which that would have not entered into market, may experience weakness to gain a significant amount of the overall market value.

Presentation of Analysis

As mentioned before we assume partial PCI during operation phase of the investment. For the estimation of the optimum deployment strategy of the investment we follow the rule suggested by Benaroch and Kaufman [4] and applied by Iatropoulos et. al. [8].

Decision Rule: Where the maximum deferral time is T, make the investment (exercise the option) at time te, $0<t_e<T$, for which the option, OVcte, is positive and takes on its maximum value.

$$OVct_e = \max_{(t=0\ldots T)} OVct \qquad (7)$$

Next, we present the results of our analysis for three exercise times, t_e=1, 2, 3 (Figure 3). We estimate the OV_{tec} for various values of expected arrivals rates of competitors during operation period $\sigma_{\lambda o}$. We model partial PCI assuming that c_o is smaller than c_w. Finally, we examine only one case of correlation between V, c_w, c_o and λ_o, which is zero correlation.

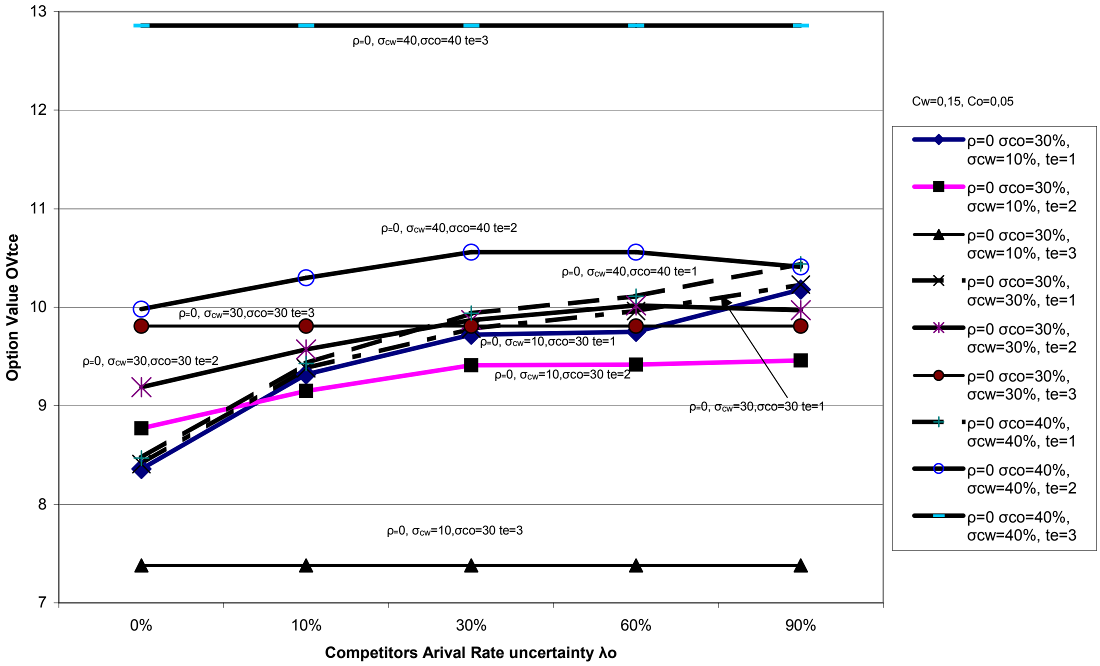

Fig. 3. The effect of the expected competitors arrival rate λ_o, competitive erosion c_w, c_o uncertainty on option value under partial PCI (zero correlation between competition parameters and overall investment revenues V, r=5%, λ_w=1, λ_o=1, σ_v=40%, V=100, X=100, t_e=1,2,3)

As it can be seen, the longer WaS period may indicate higher option values, for the specific values of competition parameters taken here, despite PTC to eliminate part of the investment value.

In general as mentioned before, it is a matter of compensation between, uncertainty control assured by ROs thinking and competition threat caused by the incoming competitors during WaS and operation period for the IO. In our example, we consider that the maximum length of WaS period is 3 years.

When IO decides to enter the market at the latest point, t_e=3, IO experiences only PTC since all the competitors who decide to enter the market will do it earlier or simultaneously with IO.

The optimum time for the IO to enter the market depends on the competition parameters λ_w, λ_o, c_w, c_o the investment revenues V as well as the existing uncertainties levels for all these.

As it can be seen, at t_e=3, the option value takes the highest value concerning a high level of uncertainty for σ_{cw}, σ_c (i.e. 40%), while for low level of uncertainty, σ_{cw}, σ_c (i.e. 10%, 30%), the option value is giving the smaller value. Since, at t_e=3 no competitors are expecting after this point, the impact of the competitors' arrival rate uncertainty $\sigma_{\lambda o}$ does not influence to the option value at all. The option values for exercise times at t_e=1,2 are between the aforementioned cases.

The conclusion is that the higher amount of uncertainty for competition parameters for both WaS and operation period, indicates higher option values for the IO indicating longer WaS period. This is the core idea of the ROs analysis. The higher amount of uncertainty existence during Was period indicates higher option value since more uncertainty will be resolved.

4. Conclusion and Future Research

This paper investigates the impact of Preemption Threat from Competitors (PTC) to the value of ICT investment opportunities, modeled as ROs. We relax existing literature assumptions considering uncertainties for the aforementioned competition modeling parameters. The results of our models prove that sometimes it is more preferable to adopt longer WaS period for an investment opportunity despite competition threat that can subtract part of it.

A limitation of our model can be in the way we estimate the up and down coefficients in the multi-diffusion process for the competition parameters. We adopt the risk neutral probabilities for competition parameters in a similar way as the overall market value V. These assumptions may be an issue of criticism that requires further discussion for their validation. However, our intention is to show how the uncertainty in competition parameters influences the value of a future investment opportunity being treated as RO.

In our analysis we consider one time step multi-diffusion process. Of course, 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. Finally, someone could adopt endogenous competition modeling assuming that each one of the competitors in the market experiences a different level of the competition parameters λ_w, λ_o, c_w and c_o. Actually, the smaller values these parameters for a player in the market are, the stronger its market position for the specific investment opportunity is. In this case endogenous competition modeling requires the integration of ROs with Game Theory.

Appendix A

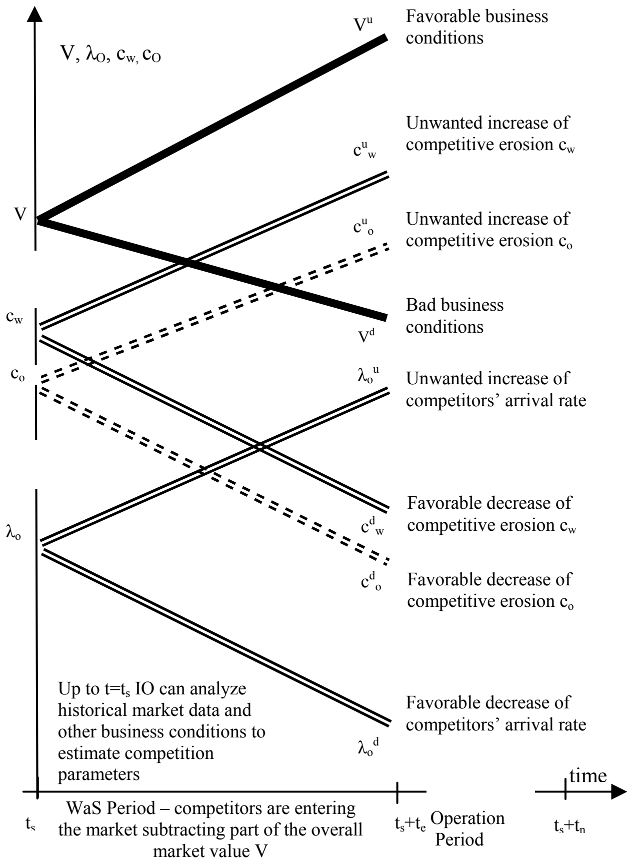

Fig. 2. Overall market revenues (V), competitive erosion (c_w), (c_o) and expected competitors arrival rate (λ_o) joint diffusion process, one time step

Because of space limitation we only present the expression that gives the option value under multi-diffusion process for competition parameters c_w, c_o, λ_o and V. The option values at expiration time (investment implementation) for the various values of c_w, c_o, λ_o and V are given by:

$$\begin{aligned}
OV^{dddu} &= \max\left(V^d - I_c^{ddu} - X, 0\right)\\
OV^{dduu} &= \max\left(V^d - I_c^{duu} - X, 0\right)\\
OV^{dudu} &= \max\left(V^d - I_c^{udu} - X, 0\right)\\
OV^{duuu} &= \max\left(V^d - I_c^{uuu} - X, 0\right)\\
OV^{dddd} &= \max\left(V^d - I_c^{ddd} - X, 0\right)\\
OV^{ddud} &= \max\left(V^d - I_c^{dud} - X, 0\right)\\
OV^{dudd} &= \max\left(V^d - I_c^{udd} - X, 0\right)\\
OV^{duud} &= \max\left(V^d - I_c^{uud} - X, 0\right)
\end{aligned} \qquad \text{(A-1)}$$

$$\begin{aligned}
OV^{uddu} &= \max\left(V^u - I_c^{ddu} - X, 0\right)\\
OV^{uduu} &= \max\left(V^u - I_c^{duu} - X, 0\right)\\
OV^{uudu} &= \max\left(V^u - I_c^{udu} - X, 0\right)\\
OV^{uuuu} &= \max\left(V^u - I_c^{uuu} - X, 0\right)\\
OV^{uddd} &= \max\left(V^u - I_c^{ddd} - X, 0\right)\\
OV^{udud} &= \max\left(V^u - I_c^{dud} - X, 0\right)\\
OV^{uudd} &= \max\left(V^u - I_c^{udd} - X, 0\right)\\
OV^{uuud} &= \max\left(V^u - I_c^{uud} - X, 0\right)
\end{aligned} \qquad \text{(A-2)}$$

$$OV_{t=t_s} = e^{-rt_e}\begin{pmatrix}
P_{uuuu}OV^{uuuu} + P_{uudu}OV^{uudu} + P_{uduu}OV^{uduu} + P_{uddu}OV^{uddu} + \\
P_{duuu}OV^{duuu} + P_{dudu}OV^{dudu} + P_{dduu}OV^{dduu} + P_{dddu}OV^{dddu} + \\
P_{uuud}OV^{uuud} + P_{uudd}OV^{uudd} + P_{udud}OV^{udud} + P_{uddd}OV^{uddd} + \\
P_{duud}OV^{duud} + P_{dudd}OV^{dudd} + P_{ddud}OV^{ddud} + P_{dddd}OV^{dddd}
\end{pmatrix} \qquad \text{(A-3)}$$

The indexes (e.g. uuuu) indicate the up and down movement of the competition parameters and V. The respective probabilities can be estimated by [5].

Appendix B

TABLE I

Parameter	Description
t_s	Time where the option is possessed for the first time by the IO and the rest of competitors.
T	Maximum deferral period in years for the option to be exercised at t_s+T. We assume that T is the same for all the competitors in the market.
t_e	Time where the option is finally exercised by the IO and the investment is implemented. Final waiting period is t_e-t_s.
λ_w	Expected arrival rate of competitors per unit time during waiting phase.
λ_o	Expected arrival rate of competitors per unit time during operation phase.
n_w	The number of competitors' entry that will take place during deferral waiting period.
n_o	The number of competitors' entry that will take place during operation phase where the option is still possessed by the competitors in the market.
c_w	The expected competitive erosion that each competitor's entry in the market will cause to the IO's investment revenues value during waiting period, $c_w=(V_{\text{before entry}} - V_{\text{after entry}})/V_{\text{before entry}}$. ($g_w$=1- c_w)
c_o	The expected competitive erosion that each competitor's entry in the market will cause to the incumbent's investment revenues value during operation period, $c_o=(V_{\text{before entry}} - V_{\text{after entry}})/V_{\text{before entry}}$. ($g_o$=1- c_o)
V	The overall market value for the growth investment opportunity.
OV_{cte}	Option value under exogenous competition modeling when it is exercised at $t=t_s+t_e$.
I_{cwT}	Total competitive erosion during waiting period up to t_s+T
I_{cwte}	Total competitive erosion during waiting period up to t_e, where $t_s<t_e<t_s+T$
I_{co}	Total competitive erosion during operation period after option exercise at $t=t_e$. If I_{cwT}-I_{cwte}= I_{co} the incumbent has no preemption capability, while if $I_{cwT}-I_{cwte}<I_{co}$ has preemption capability. If I_{co} =0 there is full preemption capability for the incumbent (PCI)
I_c	I_{cwte} +I_{co}, total competitive erosion cost.
V_f	V-I_c. Final investment revenues for the incumbent.
r	The risk free interest rate
X	Investment One-time cost
σ_v	Investment revenues uncertainty V
$\sigma_{\lambda w}$	Expected arrival rate λ_w uncertainty (volatility)
$\sigma_{\lambda o}$	Expected arrival rate λ_o uncertainty (volatility)
σ_{cw}	Competition effect c_w uncertainty (volatility)
σ_{co}	Competition effect c_o uncertainty (volatility)

Notations used in the Proposed Mathematical Model

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