Telecommunications Networks Planning and Evaluation with Techno-Economic Criteria

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Abstract. In this thesis a new tool for technoeconomic analysis has been developed. This tool is analytically presented as well as the methods that have been followed. Thesis methodology has been applied in case studies for 3G networks as well as fixed wireless and wireline access including real option and game theory approach and sensitivity and risk analysis.

Keywords: Techno-economic Analysis, Telecommunications, Demand Forecast, Real Options, Game Theory, Investments, Risk Analysis

Introduction

In this thesis we illustrate a complete methodology approach for the technoeconomic analysis of telecommunication networks that hereafter is implemented in specific detailed telecommunication case studies, wireless or wireline technologies. In the first part of this Thesis, following this methodology approach, a new tool for technoeconomic analysis has been developed. This tool is analytically presented as well as the methods that have been followed. Within this tool analysis, the theoretical approach for the cost evolution of the telecommunication components, the methodology for the demand forecast for telecommunication services and products, the approach for calculating the operation, administration and maintenance cost of the telecommunication network as well as the integration of the risk analysis model that quantified the influence of the critical parameter of the problem have been analytically presented. In the second part of this thesis the methodology has been applied in case studies for 3G networks as well as fixed wireless and wireline access (including FTTx solutions). For these case studies the real option theory has been applied, in order to clearly define the uncertainty of the investment. In addition, a game theory approach for a competition model between an incumbent and a newcomer operator has been analyzed. Finally the technoeconomic tool has been used, for the definition of a viable approach, for the provision of broadband services

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in less competitive areas in Greece, including sensitivity and risk analysis (not including in this paper).

Techno-economic methodology

The techno-economic evaluation of the case studies has been carried out using the methodology introduced and the tool presented hereafter. The TITAN project [1] developed a model that predicts the cost evolution of the network components and is based on a combination of learning curves and logistic models. In addition, for each network component, the prediction uncertainties have been specified as a function of time. The learning curve model, which presents the cost of a component as a function of production volume, can be transferred to a model predicting the costs as a function of time, by the introduction of a logistic model. The original methodology and tool have been enhanced to be able to cope with complex multimedia service and network structures. Furthermore, the methodology has been improved especially in the definition of services and assessment of operations, administration and maintenance costs. As for the maintenance cost, it is defined separately and is automatically included in the model. The operation and administration cost of the Network elements are user-defined. The life-cycle cost (LCC) of the network is then produced by adding OA&M (Operation Administration & Maintenance) costs and IFCs (Installed First Costs). Finally, the overall financial budget is calculated for the various architectures by comparing the LCC to the overall revenue. This method has been followed by several telecommunication operators in Europe [2][3][4] (e.g. Deutsche Telecom, France Telecom, Telenor, Swisscom, Telecom Italia, KPN) affecting their investment policy for new services.

Structure of the Tool for Techno-Economic Evaluations.

Fig. 1 analyses the main principles of the methodology used in this thesis [5]. The cost figures for the network components have been collected in an integrated cost database, which is the "heart" of the model. This database is frequently updated with data obtained from the major telecommunication operators, suppliers, standardization bodies and other available sources. These data concerns the initial prices for the future commercial networks components as well as a projection for the future production volume of them. The cost evolution of the different components derives from the cost in a given reference year and a set of parameters which characterizes the basic principles of the component. For each component in the database, the cost evolution is estimated according to the model described in the next paragraph. In addition, estimations for the OA&M cost and the production volume of the component are incorporated in the database. As a next step in the network evaluation a services specification is needed which will be provided to the consumers. The network architectures for the selected set of services will be defined, and a geometrical model or a radio model, will be used in order to calculate the length of the cables (or the number of the Radio stations) as well as the civil works for their installation (database data). The future market penetration of these services and the tariffs associated with them, according to each operator's policy, will be used for the construction of the market evolution model. The operator tariff policy could be taken into account by modifying the tariff level in conjunction with the expected penetration of the offered services. Results from statistics or surveys can be easily integrated into the tool when formulas measuring the impact of tariff level to the saturation of the services are available.

By entering the data into a financial model we calculate the revenues, investments (and IFC) cash flows and profits (or other financial results) of the study network architectures for each year of a project's study period. In the final evaluation of the techno-economic model, critical indexes are calculated in order to decide about the profitability of the investment.

This tool has been proved that is able to evaluate project of different scale as well as completely different and independent telecommunication technologies. The adoption of alternative financial (real options approach) and strategic methods (game theory) can be included in the tool as will be illustrated in this paper.

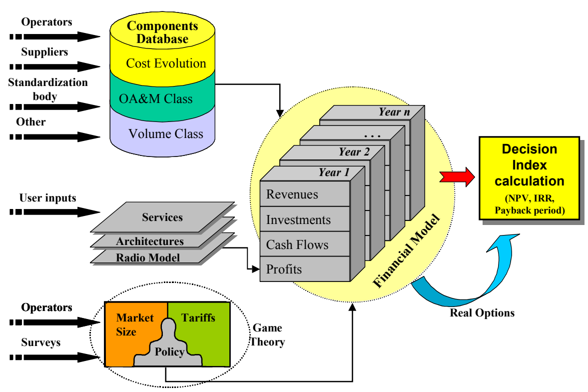


Fig. 1. Techno-economic methodology and Tool [5].

Cost Evolution Of The Network Components.

The cost prediction curve is dependent on a set of parameters such as reference cost at a given time, the learning curve coefficient that reflects the type of component, penetration at the starting time and penetration growth in the component's market. The cost database contains estimation on these parameters for all components and generates cost predictions based on the extended learning curve. The forecast function for the evolution of the relative accumulated volume $n_r(t)$ is illustrated in Eq. (1)

$$n_r(t)=\left(1+e^{\left\{\ln\left[n_r(0)^{-1}-1\right]-\left[\frac{2\cdot\ln 9}{\Delta T}\right]\cdot t\right\}}\right)^{-1} \qquad (1)$$

The expression for $n_r(t)$ can be substituted into a learning curve formula Eq.(2) yielding the final expression for price versus time in the cost database.

$$P(t)=P(0)\cdot\left[n_r(0)^{-1}\cdot n_r(t)\right]^{\log_2\cdot K} \qquad \text{or}$$

$$P(t)=P(0)\cdot\left[n_r(0)^{-1}\cdot\left(1+e^{\left\{\ln\left[n_r(0)^{-1}-1\right]-\left[\frac{2\cdot\ln 9}{\Delta t}\right]\cdot t\right\}}\right)^{-1}\right]^{\log_2\cdot K} \qquad (2)$$

where $n_r(0)$ is the relative accumulated volume in year 0. The value of $n_r(0)$ should be equal to 0.5 for components that exist in the market and their price is expected to be further reduced due to aging rather than due to the production volume (i.e. very old products-many years in the market). From estimations in industrial telecommunication network components, $n_r(0)$ could be 0.1 for mature products and 0.01 for new components in the market. P(0) is the price in the reference year 0, ΔT is the time for the accumulated volume to grow from 10 % to 90 %, and K is the learning curve coefficient. K is the factor that causes reduction in price when the production volume is doubled. The K factor can be obtained from the production industry, mainly the suppliers. For a component (with constant nr(0)=0.1) that the ΔT is equal to 10 years and K is equal to 0.98, Eq. (2) gives almost 2% of reduction in the price of the component per year for the first 10 years. If ΔT is 5 years, this reduction is almost 4% per year for the first 5 years. All the above described values have been extensively used for the evaluation of telecommunications investment projects.

OA&M Approach.

The Operation Administration and Maintenance (OA&M) approach is divided into three separate components as follows:

1. The cost of repair parts
2. The cost of repair work
3. The Operation and Administration cost for each service cross-related to the number of customers or to the number of critical network components.

The formula for calculating OA&M cost is given by:

$$(OA\&M)_i=\frac{V_{i-1}+V_i}{2}\cdot\left(P_i\cdot R_{class}+P_l\cdot\frac{MTTR}{MTBR}\right)+OA \qquad (3)$$

where V_i is the equipment volume in year i, P_i is the price of cost item in year i, R_{class} is the maintenance cost percentage for every cost component, P_l is the cost of a single working hour, MTTR is the mean time to repair and MTBR is the mean time between repairs for the cost item in question. The first term into the parenthesis represents the cost of repaired parts, the second term represents the cost of repair work, while OA represents the Operation and Administration cost. In order to implement the calculation of the OA&M cost, classes for MTTR and MTBR are defined in the database of the technoeconomic tool as well as values for P_l and P_i.

Market Analysis

The demand modelling and broadband forecasts are essential inputs to all business case analyses. Therefore, demand models and forecasts for different access technologies in the fixed and mobile network have been developed in this thesis. In addition, models have been developed for forecasting the total broadband penetration in Europe. Forecasts have been made based on a four-parameter logistic diffusion model [6] which is recommended for long-term forecasts as well as for new services [2]. The model and the values employed are based on a compilation.

The demand model is defined by the following expression:

$$Y_t = \frac{\mathrm{M}}{(1+\exp(a+bt))^c} \tag{4}$$

where *Yt* is the demand forecasted at time *t* and *M* is the saturation level of the penetration which is estimated a-priori. The parameters *a*, *b* and *c* are be estimated by a stepwise procedure, attempting to value these parameters using non-linear regression and data from of external reports and market surveys.

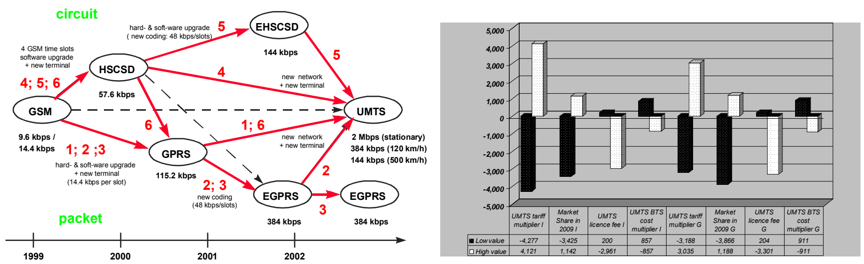
Selected Cases Studies

In the second part of this thesis the methodology has been applied in case studies for 3G networks as well as fixed wireless and wireline access (including FTTx solutions). For these case studies the real option theory has been applied, in order to clearly define the uncertainty of the investment. In addition, a game theory approach for a competition model between an incumbent and a newcomer operator has been analyzed. Finally the technoeconomic tool has been used, for the definition of a viable approach, for the provision of broadband services in less competitive areas in Greece, including sensitivity and risk analysis.

The financial perspective of the mobile networks in Europe

This case study presents a techno-economic evaluation of 3G roll-out scenarios in two “typical” European countries with contrasting profiles, analyzing both the incumbent and newcomers business cases. The analysis is based on the techno-economic methodology developed within this thesis. Market and tariff forecasts as well as the technological evolutionary paths are discussed and financial figures are analyzed. Sensitivity analysis follows these basic results in order to identify the impact of uncertainties and risks. The success of such an investment project is mainly depended on the regulatory framework, demand and tariff structure and the market share.

Fig. 2a illustrates these different evolution paths. While the intermediate steps are overlaid onto a GSM network, UMTS requires full buildout of the radio access subsystem. Incumbent operators may, however, re-use existing GSM sites. This is a major advantage for an incumbent operator in order to provide advanced multimedia mobile services.



	UMTS tariff multiplier I	Market Share in 2009 I	UMTS licence fee I	UMTS BTS cost multiplier I	UMTS tariff multiplier G	Market Share in 2009 G	UMTS licence fee G	UMTS BTS cost multiplier G
■ Low value	-4,277	-3,425	200	857	-3,188	-3,866	204	911
□ High value	4,121	1,142	-2,961	-857	3,035	1,188	-3,301	-911

Fig. 2. a) Mobile evolution steps and b) Sensitivity analysis results. Change in NPV compared to base value (4,961 M€) in case of large country both for Incumbent (I) and Greenfield (G) case [5]

The techno-economic prospects for a new entrant and especially for an incumbent operator planning to deploy the UMTS technology are found to be positive according to the base scenarios of this study. However, after investigating the sensitivity of NPV (**Fig. 2** b) to factors such as market share, tariffs, license costs, and base station costs, we draw the reader's attention to potential pitfalls. Specifically, the following elements were identified to have major consequences on the profitability of this new business:

- Regulatory decision to promote competition: By deciding to open the UMTS market to at least four competing operators, regulators are hoping that the competitive dynamics will work to offer the widest range of services to the most customers possible at least cost. However, overcrowding leading to an end market share of 10% results in negative NPV for both the incumbent and greenfield operators. Conversely, NPV is improved by 1,200 M€ for a 5% increase in market share in 2009.
- Cost of licenses: License fee and therefore the license assignation mechanism (auction or comparative hearings) can seriously deteriorate the business case since the payback period can be delayed by more than a year, together with significantly decreasing NPV. License fee increasing from 10 to 150 €/inhabitant decreases the NPV by 66% for the incumbent.
- Tariffing of voice and data services: The tariff level ranks first over service penetration and market share as the most significant factor for UMTS profitability. This result seems logical since, in NPV calculation, the tariff level directly impacts total revenues, whereas the other parameters affect the number of customers, and hence the costs. Nonetheless, it must not be construed that operators are free to hike tariffs as they wish to achieve a positive result. Indeed, the competitive

context and dropping prices for fixed network services will severely limit their room to maneuver in this area.

- Investment schedule: Since operators deploy the radio network, using a coverage rather capacity approach (mainly due to license obligation) the cost of BTS equipment incurs a heavy financial burden. Although increased BTS cost has limited impact, it leads to larger investments in the pre-service year.

In conclusion, UMTS operators will have not very much latitude to roll out their networks. Heavy investments are required early on in order to cover the most dense areas, and then once again for the suburban areas. Competitive pressure will keep tariff levels low, and operators will need to consolidate their market assumptions with extreme care in order to evaluate the payback period. Lastly, they must have enough financial resources to stay in debt for a long period of time.

Advanced Access Networks – Use of Real Options Approach

The following case is examined: an incumbent operator offering existing services over twisted copper pairs such as POTS, ISDN and dial-up based Internet service, starts offering wideband and broadband services in 2000 using his existing copper plant. At some future date, the operator may decide to install fibre closer to the customers and thereby be able to increase customer reach and offer more advanced services over VDSL. The investment problem is illustrated in **Fig. 3**a.

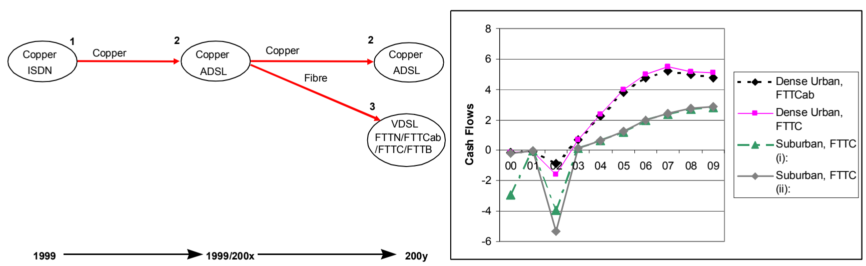


Fig. 3 a) Broadband access network investment problem and b) Cash Flows of the selected cases

The four selected strategies are: Dense Urban, FTTCab, Dense Urban, FTTC Suburban, FTTExch-FTTCab-FTTC (Suburban FTTC (i)) and Suburban, FTTN-FTTC (Suburban FTTC (ii)) The calculated Cash flows of the four operator strategies are shown in **Fig. 3**b.

In a dense urban area, the initial coverage of high-speed ADSL and VDSL services is quite high due to the short average loop length compared to a suburban area. The difference between the investments for the FTTCab and FTTC strategy is balanced by the difference in revenues. The NPVs of the four rollout strategies, when using a traditional approach, are calculated as 13.1, 13.2, -0.1 and 1.6 MEURO respectively. The Suburban FTTC (i) would therefore be rejected. Moving to the discussion in the introduction, we now turn to the assessment of the alternatives using the methodology of Real Options. First, the cash flows and their constituencies (revenues, investments etc.) are divided into two phases as in explained in [7][8][9]: the cash flows that stem from the initial service offering and the cash flows that result directly from a fibre upgrade. These phases will be denoted Phase 1 and Phase 2 respectively in the following discussion. An adjusted NPV for Phase 2 (and therefore the whole project) that includes the value of the flexibility in timing of the upgrade and the time value of money is calculated by the use of Black-Scholes [8] formula for European call option as described in [10]. The total project NPV is then calculated as the sum of the NPV of Phase 1 and the adjusted NPV of Phase 2. In order to find the value of the option of investment deferral, five parameters are required. These five parameters which are normally used in the calculation of financial call options are summarized in Table 1 along with their "interpretation" in an investment context.

Table 1 Analogy between investment opportunity and call option

Investment Opportunity	Variable	Call option
Present value of a project's operating assets to be acquired	S	Stock price
Expenditure to acquire the project's assets	X	Exercise price
Length of time the decision may be deferred	T	Time to expiration
Time value of money	r_f	Risk-free rate of return
Riskiness of the project assets	σ^2	Variance of returns on stock

The Suburban FTTC (i) strategy was used for the example. As seen, the adjusted NPV is positive compared to the negative NPV obtained from the "traditional" NPV method! The decision not to go for the investment is therefore changed to: invest in FTTCab now – then wait a few years – and then invest in FTTC! **Fig. 4** shows the traditional NPVs compared to adjusted NPVs with volatilities of 40% and 60% for the Suburban FTTC strategies:

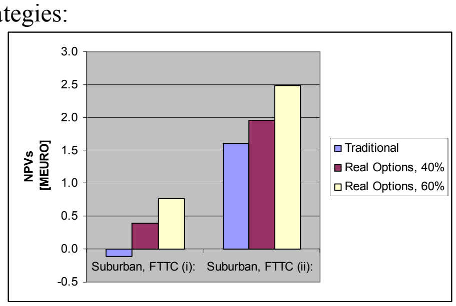


Fig. 4 NPVs for Suburban area strategies

In the FTTC (i) strategy, the decision is changed as already mentioned. For a volatility of 60% the NPV is 0.77 MEURO compared to the –0.1 MEURO using the traditional approach! In the FTTC (ii) strategy, the change in NPV is 22% and 55% respectively for the two values of volatility. If a traditional NPV methodology had been used, the broadband project would not have been initiated at all with the given assumptions because the NPV of Phase 1 is negative. The uncertainty, here described by the volatility, always has a "good" and a "bad" side. If for example the demand for new services turn out to grow faster than expected, equipment prices drop faster than expected etc., investment is considered. Otherwise, the investment decision is deferred. In cases where the sign is not changed when using Real Options, significant improvements in NPV can still be obtained due to value of the built in option. In the FTTC (ii) case with volatility of 60%, the built in option of this project (the value of the call option minus the traditional Phase 2 NPV) is even exceeding the traditional NPV of the whole project.

A Game Theory modeling approach for 3G Operators

This case study presents the technoeconomic evaluation of a 3G rollout scenario followed by the identification of the market conditions for two operators in a simple game theory model. The considered scenarios reflect the point of view of both dominant operators and new entrants. Technoeconomic results are presented in terms of net present value (NPV), acting like the pay-off function in the proposed theoretical Game Theory model.

The calculations were based on two main inputs from the TE model results (case 1 of this paper) and the hypothetical (empirical) market parameters. TE model served as the main root for calculating inputs of our calculations. So we accepted all the suppositions built into the TE model, and different models for "incumbent" and "newcomer" were prepared. We followed the 10-years time horizon, and naturally all the investments, costs and revenue figures. All the other basic parameters were set to illustrate an "average western European case".
To be able to calculate the pay-off, two important parameters were picked up, namely:

- The market share and
- the price

Within the Eurescom P901 (EURESCOM 2001) an improved model for the definition of the market behavior have been proposed. A general "S-like" curve was supposed, with three (3) sort of market behavior regarding price-reaction of customers. This kind of function stands for both companies, but with different parameters. In our calculation market function is built from the newcomer operator (player 2) point of view. All the parameters refer to the newcomer. The Market Share of the new comer is given by:

$$MS = MS_{Start} + \Delta MSD_{Min} + \Delta MSD_{Max} \cdot e^{-e^{\left(a+b\frac{TM1-TM2}{\sqrt{1+TM2-TM1}}\right)}} \quad (4)$$

Where,
MS : Market share

MS_{Start} : Market share at the beginning, where decision is made

$\Delta MSD_{Min}, \Delta MSD_{Max}$: Minimum and maximum of market share changes (delta)

TM_1, TM_2 : Tariff multiplier of player 1 and player 2 respectively.

Analytically in Fig. 5 Data Flow between TE Tool and Game Theory Tables. the data flow between the Technoeconomic tool (3G operator model) and the Game theory tables are illustrated.

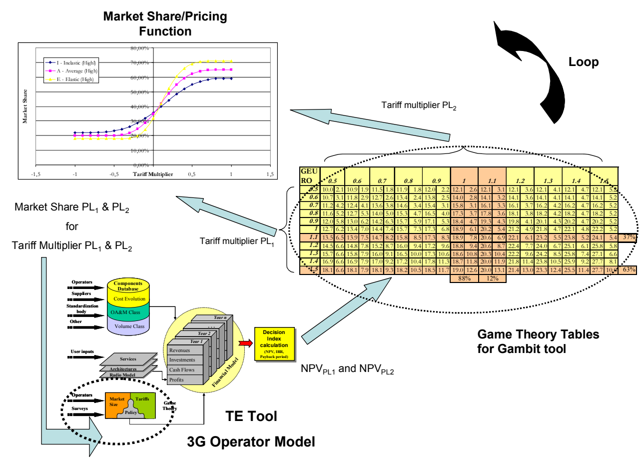


Fig. 5 Data Flow between TE Tool and Game Theory Tables.

For each point define by a specific tariff policy via the tariff multipliers exist one market share for each player (player1 – incumbent, player 2 – new comer). In the next step for each value of the tariff multiplier and market share one value of NPV per player can been calculated by the TE tool (NPV_{PL1} and NPV_{PL2}). These NPVs values are stored in a cell, consist as a step for the players for Gambit Tool. The process continues until all cells completed with NPVs values, (last step [TM_{PL1}, TM_{PL2}]=[1.5, 1.5]). These results are basically all the sensitivity results for all combinations. The process will be repeated for all defined market types Insensible-Small, Medium, High], [Average-Small, Medium, High] και [Sensible-Small, Medium, High], 9 times in total.

The following tables (in B€) show the results reached by calculating pay-off functions and in addition the Nash-equilibrium points are illustrated. Each cell contains two figures. The first column is the tariff multiplier of player 1 (PL_1) and the first row belongs to player 2 (PL_2). Each cell defined by the tariff multipliers contains two values. The first value is the NPV of Operator 1 (NPV_{PL1}) and the second is the NPV of Operator 2 (NPV_{PL2}) for a specific tariff policy. (i.e. First cell [0.5, 0.5] means 50% reduction in tariff compared to the base tariff for both players and NPV_{PL1}=9.9B€, NPV_{PL2}=2.2 B€.). The "position" of each player can be improved if its financial result is higher. The crossings of the vertical and horizontal colored differently cells show the Nash-equilibrium points. The Nash-equilibrium points are bordered differently and so do strategies of competitors bound to the equilibrium. In case of having solutions with mixed strategies probabilities of specific strategies, these are put at the end of rows or columns (i.e. Table 2 82% and 12% probability). Important to notice that these strategy combinations and equilibrium points should be seen as being Nash-sense, and even if we might speak about strategy likely to be followed, the general meaning of this, is different from i.e. "dominant strategy".

Table 2: Pay-off matrix of HA version (High market share, Average market)

	0.5		***0.6***		***0.7***		***0.8***		***0.9***		***1***		***1.1***		***1.2***		***1.3***		***1.4***		***1.5***		
0.5	10.0	2.1	10.9	1.9	11.5	1.8	11.9	1.8	12.0	2.2	12.1	2.6	12.1	3.1	12.1	3.6	12.1	4.1	12.1	4.7	12.1	5.2	
0.6	10.7	3.1	11.8	2.9	12.7	2.6	13.4	2.4	13.8	2.5	14.0	2.8	14.1	3.2	14.1	3.6	14.1	4.1	14.1	4.7	14.1	5.2	
0.7	11.2	4.2	12.4	4.1	13.6	3.8	14.6	3.4	15.4	3.1	15.8	3.1	16.1	3.3	16.1	3.7	16.2	4.2	16.2	4.7	16.2	5.2	
0.8	11.6	5.2	12.7	5.3	14.0	5.0	15.3	4.7	16.5	4.0	17.3	3.7	17.8	3.6	18.1	3.8	18.2	4.2	18.2	4.7	18.2	5.2	
0.9	12.0	5.8	13.0	6.2	14.2	6.3	15.7	5.9	17.1	5.3	18.4	4.7	19.3	4.3	19.8	4.1	20.1	4.3	20.2	4.7	20.2	5.2	
1	12.7	6.2	13.4	7.0	14.4	7.4	15.7	7.3	17.3	6.8	18.9	6.1	20.2	5.4	21.2	4.9	21.8	4.7	22.1	4.8	22.2	5.2	
1.1	13.5	6.5	13.9	7.5	14.7	8.2	15.8	8.5	17.3	8.3	18.9	7.8	20.6	6.9	22.1	6.1	23.2	5.5	23.8	5.2	24.1	5.4	37%
1.2	14.5	6.6	14.8	7.8	15.2	8.7	16.0	9.4	17.2	9.6	18.8	9.4	20.6	8.7	22.4	7.7	24.0	6.7	25.1	6.1	25.8	5.8	
1.3	15.7	6.6	15.8	7.9	16.0	9.1	16.5	10.0	17.3	10.6	18.6	10.8	20.3	10.4	22.2	9.6	24.2	8.5	25.8	7.4	27.1	6.6	
1.4	16.9	6.6	16.9	7.9	17.0	9.2	17.2	10.4	17.8	11.3	18.7	11.8	20.0	11.9	21.8	11.4	23.8	10.5	25.9	9.2	27.7	8.1	
1.5	18.1	6.6	18.1	7.9	18.1	9.3	18.2	10.5	18.5	11.7	19.0	12.6	20.0	13.1	21.4	13.0	23.3	12.4	25.5	11.4	27.7	10.0	63%
											88%		12%										

Having Nash-sense equilibrium practically means both competitors play their best strategy, related to the other strategies selected. This can be done only in such a way, that players know each other's strategy in advance. Within limits, this could be a real situation. Formation of mixed strategies as solutions means that unambiguous or simple strategies do not exist in order to reach equilibrium. Of course, the reader might define other kind of equilibrium condition than Nash-sense, e.g. managers may be interested in strategy being "the best" independently of other players' strategy-selection, or what happens if all the other players work the ruin of the others. In the first case we can reach "dominant strategy" and in the second we would have in our hands "the safe strategy", both being a kind of equilibrium.

Falling back on our Nash-equilibrium points, and having mixed strategy solutions, the operators should play on a "statistical base", and choose strategies relying on numerical possibilities. As this seems to be rather "unrealistic", operators would likely follow a strategy of higher probability value. Quite independently of initial market share of the newcomer and type of market, newcomer has to have always smaller prices, as the market analyzer might feel that this is "natural". In most of our results this offers quite small tariffs compared to the incumbent operator's ones.

As initial market share of newcomer increases, both competitors should decrease their prices, but regarding our inelastic total market models, incumbent always has a chance of having "the highest" price, being viable at the same time (quite positive NPV). It is interesting that with increasing sensibility of the market the solutions exist only with mixed strategies. This means that the mutual impact of competitors on each other, assumes that players have investigated what the other player does, deeply into statistical decision making "process".

Conclusions

Concluding, investments in telecommunication technology can develop a new market area and expand traditional options for new players. Any business modelling should be accompanied by technoeconomic evaluation in order to give readers insights into the financial perspective and viability of a telecommunication investment project. In addition real options approach should be a complement to existing capital-budgeting systems and NOT a substitute of them. Game theory should be followed in order to have a better understanding of the competition as it effect on the financial perspective of the telecommunication projects.

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