Models and methodologies for forecasting and evolution of diffusion and competition of telecommunications markets

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Abstract. This thesis presents a methodological framework which integrates in a uniform way several important parameters influencing the progress of penetration of telecommunications products and services. Given the above methodological framework, significant problems of high-end market are faced, regarding diffusion and competition. The approaches developed are based on an appropriate mathematical and statistical background and they are applied to specific case studies, providing highly accurate results.

This thesis involves the valuation and prediction of the demand for telecommunications products and services, as well as the competition on the telecommunications market, with the use of novel methodologies based on an appropriate mathematical and statistical background. The basic scope is the improvement of the prediction capability compared to existing wide used prediction models of the specific scientific area. The total contribution involves the creation of new methodologies and the application of existing ones in the new relevant fields of application.

The objective of this thesis corresponds to an important part of the techno economic design aiming to the prediction of demand and competition in the telecommunications market. Examples of such markets are the developing broadband fiber networks and wireless mobile terminals. The design of these networks together with their expected use in the future, are important elements related to the development of the corresponding infrastructure. Due to the rapidly developing technologies and the growing demand for access, design of these networks should provide and support innovative network services and technologies. Determining the number of users, the expected utilization of services, the volume of mobile data and the shaped market shares due to competition, should be the drivers for the development of the infrastructure to support the network operation.

Both the methodologies and their results obtain added value for the case of Greece, as the country is going through a period of rapid developments in terms of telecommunications infrastructure and services development.

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1 Dissertation Summary

1.1 The problem that the thesis investigates and its primary targets – the significance of the results

The objective of this thesis corresponds to an important part of the general techno-economic design that accompanies the development and function of the telecommunications networks. It involves the review and forecasting of the diffusion of telecommunications services and products, as well as of the competition in telecommunications markets.

This thesis presents a rigorous methodological framework that integrates a uniform manner several important parameters that influence the course of penetration of telecommunications products and services. Based on the above methodological framework useful results emerged as to predict the demand for services and products, and competition in the high-tech market. These results emerged as the methodologies applied to specific case studies.

The results of this thesis, besides the high scientific interest that they present, have extra practical value under the prism of the modern markets, which are characterized by the rapid development of the broadband optical networks and of the mobile telecommunications.

The design of modern communications networks and the prediction of future penetration of the services to be provided through these networks are critical elements related to the course of development of the infrastructure. Due to rapidly developing technologies and the ever growing demand for access requirements, the design of these networks should provide and support innovative network services and technologies. The determination of the number of users, intensive use of services, the volume of mobile data and market share due to competition should be a guide for the development of infrastructure that will support the operation of the networks. In order to become the design, development and deployment of network infrastructure should necessarily precede the precise identification and prediction of intention to use the services to be provided. Otherwise there is a strong probability that a failure of planning and investment, the new network will not receive the expected acceptance and use.

The study addresses this very necessary stage of development of communication infrastructures. Particularly in the case of Greece, the results acquire added value as the country goes through a period of rapid developments in the modernization of telecommunications infrastructure and services. In addition, the boundaries between voice networks and data networks have ceased to exist, marking the convergence of electronic communications networks. The development of the Internet is a prime example of this, as with a conventional computer the average user is allowed access to services such communication (using video and audio) and data management (TV, video, radio, etc.) through the same network infrastructure. It is obvious that the convergence of networks and the emergence of new services leads to increased resource requirements and infrastructure, and to increased number

of users. Consequently, there is need for improvement and development of appropriate methodologies to address the new problems that have arisen.

Due to developments and changes that were performed on the telecommunications market, as described previously, relating both to market liberalization and the rapid technological developments, it becomes clear the need for elaboration of demand forecast studies and their integration in the respective business plans a modern telecommunications provider, in order for him to enter the market, to ensure its sustainability and to maintain or increase its share. The forecast of demand plays an important role in the administration and management of an organization, and can provide information on the technological changes that may affect their corporate objectives, identify the medium- and long-term activities and to highlight the importance disposal a technological innovation, the pace of technological substitution generations and other critical issues.

Moreover, the effect of increased competition in the telecommunications market and the continuous emergence of new products led to increasing problems associated with forecasting the demand facing both the providers and regulators and other stakeholders. The providers and manufacturers failed to produce reliable forecasts for demand for products or services, on which to base their business plans, can have dramatic effects that can be associated with either failure or by an excess supply on the market.

Rapid technological progress has resulted in the provision of a multitude of new products and services, while the market has not been accompanied by corresponding research for the study of penetration in the relevant market. The relevant research work has remained largely in the form of monopoly of the telecommunications market, in which only the active state, and dominant provider in which the incidence of technological innovations was quite slower. Consequently, it is now necessary to research activity in this direction in order to address current problems relating to demand forecasting.

The forecast of demand remains a critical factor because it is part of a broader economic analysis of the telecommunications market becoming a key input in the coming stages. The most representative case is usually treated in the telecommunications market which is directly dependent on the results of prediction of penetration is the dimensioning of the network and other infrastructure should be developed to support the growing demand for the services offered. The above example shows that the accuracy of the results of forecasting is an extremely critical factor, mainly because of its link with the required investments.

The major contemporary problems relating to the provision of the telecommunications market demand and that highlight the need for developing further research in this area are described below.

The first of these problems concerns the description of the very modern telecommunications market, which now is oligopolistic or competitive, which no longer includes only the sovereign, government, providers and alternative providers. Current services are not only limited to fixed voice communications, but also include mobile communications and data communications, and video.

In addition, the boundaries between voice networks and data networks have ceased to exist, marking the convergence of electronic communications networks. The Internet is the most typical example of this, as with a conventional computer the average user is allowed access to services such communication (using video and audio) and data management (TV, video, radio, etc.) through the same network infrastructure.

For the incumbent, who until now operated in a monopolistic market, increasing handling voice and data was disturbed by the market entry of alternative providers. This leads to research questions, in order to consider the new form of market arose. Considering however that the telecommunications market is characterized by specific entry barriers (market entry barrier), there is a need to develop new approaches and adapting existing ones in order to study the relevant competition issues arising.

As a direct consequence, there is higher competition between providers on the pricing policy in order to maintain and increase their market share. By extension, the disposal value of a service is expected to have a direct influence on the penetration, even creating a field of research which concerns the study of price elasticities and advertising on the service demand.

The emergence and rapid spread of mobile technology has created further research issues related to the substitutability and complementarity of the services provided. For example, there are still uniquely identified questions regarding whether the mobile telephony gradually replacew the stable.

Another important category of contemporary problems in the field of forecasting demand in the telecommunications market relates to the time range of forecasts. In this connection there are two directions of research interest: short-term and long term prediction, which face different demand. In the direction of short-term forecasting, among the problems is the prediction of the movement of the users of providers (churn effect) and burden of network traffic, aiming primarily to determine the economic impact and the use of an appropriate range of infrastructure and staff to meet demand needs. The long-term demand forecasting includes issues relating mainly to the potential entry of new providers in the market, the progress of penetration of new products and services and levels of market saturation in demand service. The prediction of the course of penetration of a new product on the market is an extremely important and complex problem, given the rapid development of technology, which has resulted in the continuous emergence of new or differentiated products and services, which often are not available recorded history data to predict the subsequent course.

All these issues are both research and practical problems involving all stakeholders in the telecommunications market: the regulators, providers, manufacturers, and even end users. Furthermore, raise research interests, around which the existing literature is incomplete, thus substantiating the need for further research in the same area.

1.2 Other relevant research efforts that have been nominated in the bibliography

There is a large number of studies focusing on modeling the diffusion of innovations, aiming to provide accurate estimates and forecasts. The increasing academic interest in this area began in the 1960s, when a significant number of related papers

came to light. Fourt and Woodlock [1], Mansfield [2], Floyd [3], Rogers [4], Chow [5] and Bass [6] were the first to consider the modeling of a technology's diffusion. Their work has encouraged many modifications often adopted and studied, even in recent research efforts.

Time series were mainly studied under a deterministic prism, until Yule [7] introduced the notion of stochasticity in 1927. According to him, every time-series approach can be regarded as the realization of a stochastic process. This simple idea launched a number of time-series methods, varying in parameter estimation, identification, model checking and forecasting. Nevertheless, it was the work of Box and Jenkins in their publication Time Series Analysis: Forecasting and Control [8] that integrated the existing knowledge and made a breakthrough in the area. The Box-Jenkins approach is a coherent, versatile, three stage iterative cycle for time series identification, estimation and diagnostic checking. The evolution of computers made the use of autoregressive integrated moving average (ARIMA) models popular and applicable in many scientific fields.

The gap in research concerning the comparative performance of sales forecasting models in a given situation was underlined by Armstrong, Brodie and Mclntyre [9]. Furthermore, the use of ARIMA models has not been widely investigated in the case of forecasting the diffusion of innovations. In addition, Meade [10] stated in 1984 that the popular diffusion models are among the heavily used forecasting techniques in a corporate environment. The forecasting accuracy of ARIMA models has been compared with a selection of diffusion models, among which the models of Floyd, Bass and Gompertz [11,12], by Gottardy and Scarso [13].

Exponential smoothing methods have been around since the 1950s, and are still among the most popular forecasting methods used in business and industry. Nevertheless, exponential smoothing can be used with any discrete set of repeated measurements. The major advantage of these models in providing mainly accurate short term forecasting has surprisingly led to lack of research regarding their application in long-term diffusion forecasting. Gardner and McKenzie made a breakthrough in the research area of exponential smoothing with a series of papers ([14–16]) by developing new versions of the Holt–Winters methods that damp the trend as the forecast horizon increases. Their work has stimulated the interest in this area, resulting to the inclusion of the damped trend exponential smoothing methods in the successfully applied approaches in empirical studies, as discussed by Gardner [17]. In addition, the damped trend is recommended by Armstrong [17] as a well established forecasting method that should improve accuracy in practical applications. The area of exponential smoothing has undergone a substantial revolution in the recently past years.

During the analysis of an ecosystem, the equilibrium analysis of dynamic predator–prey systems is one of the most important stages, which is described based on appropriate systems of Lotka–Volterra equations [19], the latter used to model the system dynamics [20]. The Lotka–Volterra equation, which was developed to model the interaction between the two competing species based on the logistic curve, is considered as an alternative competitive diffusion model for analysing the telecommunications market. Applications of the Lotka–Volterra equations to the analysis of technology diffusion in a competitive market can be found in relevant literature [21--23].

1.3 The main original results that risen from the thesis

The main original results that have risen from the thesis are:

- Development of a comprehensive framework for assessing and forecasting the demand in the telecommunications market, with emphasis on innovative use of time series models, independently or in combination with traditional aggregate demand models, covering all phases of diffusion. This framework is both applied and markets high technology products in general.
- Valuation methods for selecting appropriate, on a case-demand models.
- Overview of social, economic and other parameters (such as pricing) that affect the process of diffusion of a product or service in the telecommunications market with case studies.
- Implementation of chronological Grey model with a minimum of chronological data (four) at the beginning of the diffusion of innovation and verification of its effectiveness against a cumulative classic diffusion model [24].
- Creation of a diffusion model for the initial phase of diffusion of innovation that incorporates predictor of pricing based on the corresponding service of the past, that proves superior to the simple form of the cumulative diffusion model which was based.
- Combination of forecasting cumulative diffusion models and time series ARIMA models to achieve better prediction of the classical cumulative diffusion models in the middle phase of diffusion [25].
- Creation of a variant chronological cumulative trend model Holt's incorporating a cumulative forecasting parameter affected by a diffusion model in the final phase of diffusion in order to achieve improved provision against cumulative diffusion models [26].
- Development of models to assess and predict the level of competition and the concentration of the telecommunications market, based on procedures from the natural world and in particular the population biology (population biology), in which market competition is simulated with survival course of species in an environment [27-28].
- Creation of a new predictive model market share of a new entrant wireless provider using tools such as The HHI competition and diffusion models [29].
- Investigation of the use of time series models for short-term forecasting of various telecommunications markets competition indicators.

2 Results and discussion

The thesis is structured in 11 chapters. The first chapters present the concepts, methodologies, assumptions and approaches that constitute the common background of the following chapters of the thesis.

After the first introductory chapter, which gives a brief description of the investigation carried out, the second chapter followes which describes developments in telecommunications technology and in social, economic and regulatory factors affecting them, as well as a review of the history and development of telecommunications,

including with the reasons which made forecasting the demand and competition as a necessary part in the preparation of business plans in telecommunications.

The third chapter takes provides a brief review and classification of existing methodologies in the literature for the estimation and prediction of the demand. It contains a detailed description of the approach adopted for the preparation of this thesis, which is related to the diffusion theory and aggregate models, i.e. the mathematical models that describe it. These are then used in the thesis for creating an appropriate methodological framework which is implemented and evaluated the study characteristics specific cases.

The fourth chapter is extensive reference to the time series, the use of which is a key piece of research conducted in the framework of this thesis. It describes basics of time series and their use to export forecasts, as the stochastic process, measures and time series analysis, stagnation and simple time series models. Then an extensive report on time series models used in the following chapters of the thesis is presented in the context of foresight studies. First a description is provided of stationary stochastic processes with a focus on integrated autoregressive moving average models ARIMA and time series analysis with their use. Then the smoothing methods are analyzed, namely the methods of the simple and the double moving average, simple and double exponential smoothing, exponential smoothing by adjusting the voltage and exponential smoothing by adjusting the voltage and seasonality. Finally reference is made to the existing provisioning software.

The fifth chapter initially presents the application of Grey theory to produce short-term forecasts of the diffusion of a new high technology in the early stages of the process. The valuation methodology is performed using real diffusion data from European countries. After obtaining the minimum data points for the application of Grey theory (four data), a classic diffusion model, the Gompertz model, and the GM (1,1) model, are applied to the sample, leading to results that verify the accuracy of the forecasts after applying the Grey theory. The second study in the initial stage of diffusion presents a new methodology that offers short-term predictions of the diffusion of a new technology in the early stages of the process. Once enough data is gathered to make a time-series, it is applied to sample both models. A classic cumulative diffusion model and a variant of using the phenomenon of price reduction based on estimates of an older similar technology are used. This approach is based on the assumption that the influence of the price cut should be provided for the initial diffusion, even if such data are not yet available. This reduction phenomenon should be based on experience gained from previous similar cases of telecommunications technology.

The sixth chapter presents an innovative methodology combining time series and cumulative diffusion models to predict short diffusion process in the middle phase of the procedure where the data available are limited. Projections incorporate the influences of the ARIMA model and the cumulative diffusion models and are providing more accurate than any standalone application of each approach. This process avoids the use of simple means. It also avoids the use of weights (weights) as a method of combining, as it would include personal assumptions, while correlations between forecast errors are likely to change from period to period. Two popular telecommunications innovations were chosen for the implementation of the methodology (broad-

band and mobile telecommunications). The new methodology provided better predictions from each model separately in both technology and in each geographical application. Forecast combinations is a topic widely researched in the field of statistics. The one-year-ahead forecasts of each approach were compared based on three widely used measures of accuracy: the Mean Square Error (MSE), the Mean Absolute Error (MAE) and the Mean Absolute Percentage Error (MAPE), with the MAPE being the main measure, as noted in other similar studies of forecast combinations. Even though the new methodology provided better predictions than each model separately in both technologies and for every application, all three approaches provide more-or-less reliable predictions for the period considered. Another important observation is that the forecasting accuracy of the ARIMA model diminishes gradually at this stage of the growth process, from period to period, whereas the corresponding predictions of the Linear Logistic model improve. The differences in numbers may not seem of great importance. Nevertheless, these small differences represent, in reality, some thousands of new subscribers. Even though the forecasting power of the methodology seems limited, it should be taken into consideration that the forecasting improvement is for one-year horizon. This single year's improved forecast could make the difference in the sense of corporate competition, as this knowledge is a useful guideline for the upcoming year's strategy programming. The use of ARIMA models and their combination with the cumulative diffusion models not been widely explored in forecasting the diffusion of innovations, so this study collect the largest number of citations of the studies resulting from this thesis so far.

The seventh chapter presents a new methodology that offers improved long-term forecasts of the diffusion of an innovation compared with two classical cumulative diffusion models, the model of Gompertz and the linear logistic model. After collecting sufficient number of historical data for analysis by the exponential smoothing method and since diffusion has reached the inflection point of the sigmoid curve, the method of Holt’s damped trend is applied, directed by the forecasted planned saturation point of a cumulative diffusion model. The application of the method to broadband diffusion data on all OECD countries and the United States for different forecasting horizons confirmed the accuracy of prediction. Application of the method in the case of broadband penetration in the total sum of the OECD countries and the United States from 1997 until 2009, for different forecasting horizons ranging from 6 months up to 30 months forth, verified its accuracy and illustrated its performance capabilities. The forecasts of each approach were compared based on the three widely used measures of accuracy estimation, comparison and forecasting. After its validation with the hold back sample, the proposed method was applied for a 48-month forecasting horizon, until mid 2013. The proposed approach method predictability extends to long-term forecasts. This variant combines the advantages of both approaches, the cumulative diffusion models affected by the expected sigmoidal form of the process, while the exponential smoothing methods rely mainly on newly recorded historical data. This is the first time that this combination is appied for creating an innovative variant of the model of Holt, inspired and designed for the specific diffusion region.

Chapter eight describes the methodology for assessing and forecasting the development of competition in the telecommunications market and generally of high tech markets, based on the principles of population biology, which deals with the study of the evolution of the species population in the context of interaction that develops between populations and the influence of the environment in which they are located. It is this evolution of the species is in concordance with the course providers in an oligopolistic or competitive market, such as telecommunications, within the meaning of the respective market shares. In this chapter concepts of competing species (predator - prey) and a description of the respective model are presented.

The ninth chapter deals with the valuation methodology of Lotka - Volterra for the evolution of the concentration of the telecommunications market in two innovative fields of application, that of fixed telephony (PSTN) and moblie prepaid - contracts. The mathematical description of the methodology was performed using the Lotka–Volterra model, in a prey–predator mode and the corresponding parameters were estimated by the means of genetic algorithms. The proposed methodology showed itself capable of estimating market equilibrium and market concentration and it can be applied over any high technology market meeting the above characteristics, providing valuable inputs for managerial decisions, strategic planning and regulatory decisions to the players of a high technology market. The results output includes the ability of the methodology to accurately assess the extent of competition in the telecommunications market and its concentration and predict the balance point in the future. The evaluation methodology was performed using genetic algorithms, while the evaluation of the results was based on classical statistical error measures.

In the tenth chapter, special topics of the telecommunications market competition are developed. More specifically, in the first part, competition concentration indicators of the telecommunications market are calculated and the use of time series for forecasting is investigated, with an application to the providers of the Greek mobile telephony. More specifically, the commonly used mobile communications market concentration indicators are described, analyzed and evaluated for the case of the Greek mobile market, which is considered a typical representative of oligopolistic market. Moreover, forecasting using time series is applied in order to test the accuracy of short-term forecasting of such measures, which are directly affected by market events, such as mergers. The second part introduced an empirical model that predicts the later entrant's market share development in the mobile telecommunications market of a country. It can be used as a preliminary tool by the analysts of the mobile market, as well as by the potential investors interested in predicting the market's potential before the act of entry, merger or acquisition. The evolution of market share is explained by factors such as the moment of entry, the HHI at the moment of entry and the forecasted changes in the penetration rate, as estimated by the Linear Logistic model. There is strong evidence that the earlier a new operator enters the country's market, the greater potential the operator has in gaining significant market share. The model gives an overall idea of the market share development of a later entrant that can become more accurate if combined with other methods, which take into account other crucial variables, such as pricing, cost and profits. The most logical extension of the model is the inclusion of the pricing effect. The difficulty lays in the absence of an-

nounced price time-series data. The effect of the marketing potential of each operator would also improve the forecasting accuracy of the model, although the recording of such a value demands too much market information. Nevertheless, the predicted outcome of the model's application approximates the actual data, especially the «long – run» market share of the two operators.

Finally, in the final chapter, the general conclusions of the thesis as well as future research directions are presented.

3 Conclusion

The results that came up from the development and evaluation of the above mentioned methodologies provide important and direct contribution to the development of business plans and to the determination of critical decisions. They offer the capability of precise assessment and forecasting of the diffusion of an innovation, as well as of the competition level of telecommunications markets, taking into consideration the most critical factors that affect the markets' dynamics.

Regarding the researching extensions of this thesis, they evolve around the creation of a common, coherent methodological framework that deals with the phenomenon of the diffusion of telecommunications' innovations, taking into consideration all the parameters that affect it. In order to achieve the production of accurate results, it is essential to unite all the influences that are placed. The success of a diffusion process of a new product or service in a market depends directly on a great variety of factors. This methodological framework will include all the parameters that were examined in this thesis, as well as the stochastic analysis of the results. The implementation of the above mentioned framework should be accompanied by the development of the proper software so that the execution of the necessary mathematical calculations would be automatic.

In reference to the methodologies that deal with study of the competition in the telecommunications' markets and are based on the principles of population biology, among the possible research extensions is the assessment of their capabilities in other high-technology markets, that have similar characteristics with the telecommunications' market, like oligopolistic form and barriers for entrance of new players. An important extension of the Lotka-Volterra methodology is the addition of extra stochastic terms in the initial mathematical equations.

Finally, an important extension that can be applied almost to every methodology that has been presented is the inclusion of decision parameters in them, such as price and advertising, in order to evaluate their influence in the diffusion process of a telecommunications product, together with the rest of the parameters that are included in the definitions of the models.

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