The impact of economic and social environment on the diffusion of Information and Communications Technologies

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Abstract. In this PhD thesis, the impact of economic and social environment on the diffusion of Information and Communications Technologies (ICTs) is studied. Initially, broadband diffusion process in Europe is examined and suggested an approach to measure the digital convergence of countries participating in the analysis. Through a non-parametric analysis between broadband penetration and socio-economic parameters, it is shown that the impact of the influential parameters depends on the level of broadband penetration. Furthermore, a causal analysis between the economic status and the level of broadband penetration is performed in many countries. Then, a new metric, the "Utilization of Communications Network Potential" (UCNP) versus public practices aimed at enhancing new technologies is proposed. The impact of UCNP is examined in a series of socio-economic parameters. Next, a new index is introduced i.e. the "Maturity Level of ICT" (IMLI). The calculation of this index allows the ranking of countries on the basis of their economic status, highlighting best practices. Finally, a theoretical framework for developing business plans operating optical networks is developed, along with an analysis of population restrictions regarding Greece.

Keywords: Broadband, Influential Factors, Econometrical Analysis, Service Diffusion, Decision Making

1 Introduction

The development of new technologies and, particularly those which are known as Information and Communications Technologies (ICT), raises a number of entrepreneur and political considerations. In this dissertation, the impact of economic and social environment on the diffusion of ICTs is studied. The analysis is based on statistics from international data bases, econometric methods and strong mathematical tools. For assessing the reliability of results statistical measures and criteria from information theory were used. In the following sections critical questions regarding the aforementioned impact are attempted to be answered.

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Apart from the continuously increase of ICT diffusion, ICT inequality among countries, in terms of ICT investments, PC skills, Internet skills and the availability of telecommunications networks is still evident. This inequality can be described as a digital gap (or digital divide) between and within countries. Broadband services are considered as key factor of ICTs, and therefore the rate of digital convergence within European borders, in terms of broadband penetration across a number of 28 European countries is studied [1]. Digital convergence is used under the meaning of the process of homogenization of broadband diffusion, based on the status of penetration rate of corresponding countries. In addition, it is especially concerned with the evaluation of the contribution of each country to the process of broadband diffusion, as a whole. The methodology used to measure the digital divide is based on appropriate mathematical or econometrical approach and corresponding assumptions regarding the proxies used to estimate it. The digital gap is assumed to be driven and reflected by the differences in broadband penetration among European countries. An adequate index for the estimation of digital convergence is developed which in turn can be used to provide future forecasts on the convergence.

Despite of the technical characteristics, i.e. broadband penetration rate, there is a group of other important factors which play a crucial role in the process of broadband growth. The analysis of the impact of these factors on broadband adoption could lead to useful outputs and it constitutes the objective of the following analysis [2]. Towards this direction a number of socio-economic factors are assumed to influence broadband diffusion, considered responsible for the different levels of adoption among countries. Therefore, the effect of a wide range of social, economic and political factors over the broadband diffusion process is analyzed, following a non-parametric approach and comparing the results with these of the parametric. Based on criteria from information theory the link function between the level of penetration and the rest variables is derived, providing highly accurate results, during the different stages of the diffusion process, which are defined by the inflection point. The evaluation of the methodology was performed over countries from the wider European area, revealing that the influential parameters vary, depending on the stage of the diffusion cycle.

Under the present economic crisis, much discussion is made for income increase. New technologies, especially broadband, can yield comparative advantages in countries. Based on the assumption that income is related with broadband penetration, a Granger causality test is applied in 83 countries worldwide [3]. The causality case is tested separately in developed and developing countries, as far as in different level of broadband diffusion. The analysis aimed to examine the relationship (one-way or bidirectional) between Gross National Income per capita and broadband penetration level.

Technological adoption, with an emphasis on ICT, is considered as a decisive factor for the overall development of each country. For this, the European Commission (EC) has launched a number of policy frameworks, while recently EC decided to set some additional targets, in order to facilitate a wider adoption of information services and maximize economical and societal benefits. In line with this, the effect of the driving factors that accelerate the uptake of public e-services, together with the impact of technological adoption on the socio-economic status is studied [4]. A new parameter is introduced, the Utilization of Communications Network Potential (UCNP), which echoes the Information Society (IS) maturity level. An analysis, focusing on monitoring the progress of public and European Commission (EC) actions is additionally presented in order to assess the evolution of the IS maturity level in the European area. The impact of two main public depended indexes, i.e. structural and benchmarking indicators, on the UCNP maturity level is evaluated, together with the influence of the latter over socio-economic parameters.

The use of ICT turned out to be a key factor in the process of the wider development of a country. It is therefore very useful to estimate ICT evolution by the means of an appropriate metric. Based on statistical data from 159 countries, the ICT Maturity Level Index (IMLI) is proposed and estimated by using Structural Equation Modelling (SEM) [5]. This index is a metric measuring the information society in a country and consists of three sub-indices which are access, use and skills. It is an improvement of the ICT development index, proposed by the ITU in 2009. The analysis divides the countries into two groups, the developed and the developing, due to major disparities in their statistical data. The criterion used to define the groups was the income, as expressed by the Gross National Income per capita. The impact of a number of influential parameters on the ICT maturity level is evaluated and it becomes obvious that there is a substantial difference in their impact between developed and developing countries. Finally, a procedure that allows the ranking of the countries, based on IMLI, is presented.

Additionally to the above, a pool of business solutions for Metropolitan Area Networks (MANs) development, especially for the Greek case, is proposed based on detail analysis and benchmarking of international practices [6]. Finally, one of the most widely used power laws applied in demographics, the Zipf's law, is tested over urban cities in Greece. Apart from the examination of Zipf's law validation over population, the distribution of population density as far as population differentiations in the last decades are studied [7].

2 Digital Divide Gap Convergence in Europe

Despite the targeted actions initiated by the EC and the member states, there are still large differences in the corresponding broadband penetration rates [7]. However, there is still room for improvement that could lead to a higher broadband adoption. The dataset used in this analysis was extracted from Eurostat and the term penetration describes the number of connections over population (i.e. over the 28 European countries considered) [9]. More specifically, the dataset consists of 28 quarter terms, from December 2001 up to December 2009. The development of the proposed methodology is presented in the following paragraphs, in terms of the assumptions made and the mathematical framework used.

For each quarter term, t, and for each one of the considered countries, i, the proportion of its penetration over the mean penetration rate is calculated. The results are plotted against time and depict the relative penetration, RP, of each considered country and for each period of time. The formulation for calculating the RP is described by Eq.1.

$$RP_{(i,t)} = \frac{\frac{x_i}{p_i} - \frac{x_T}{p_T}}{\frac{x_T}{p_T}} \quad (1)$$

where x_i is the cumulative diffusion rate of each country at time t, and x_T is the total penetration of the considered countries, in the same time period, in terms of subscribers. In addition, p_i is the population of each country and p_T is the total population across all of the considered countries. In addition to the above calculations, the width of $RP_{(t)}$, ($\Delta(RP_t)=RP_{max,t}-RP_{min,t}$), in each quarter term is calculated.

Further analysis includes the forecasting of the future values of $\Delta(RP_t)$, which describes the future process of digital convergence. The corresponding results for both the estimated and the forecasted values of $\Delta(RP_t)$ are plotted against time, in order to provide an estimation regarding the time of full convergence. Forecasting is based on appropriate mathematical functions, originated from two representative function families, the exponential and the polynomial.

The calculated $RP_{(i,t)}$ values for all the European countries considered tend to zero, which means that countries tend to equally contribute to the total broadband diffusion in Europe. The statistical accuracy of the two functions used to provide forecast results is based on the R-squared (R^2), the Residual Sum of Squares (RSS), the Mean Square Error (MSE) and the Mean Absolute Error (MAE).

Both functions provide quite acceptable results and therefore can be expected to provide reliable forecasts as well. However, in all cases, the estimated values of statistical measures referred to exponential approach provided more accurate results.

A visual representation of the above findings is illustrated in the graphs of Fig. 1. According to these graphs, it is obvious that both functions provide accurate fittings of the actual observed values.

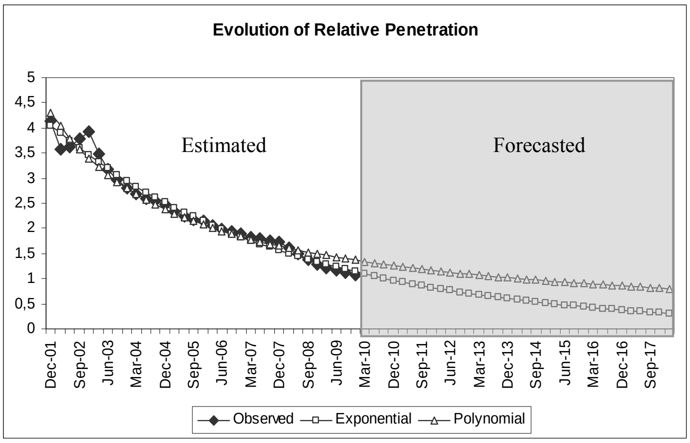


Fig. 1 Evolution of relative penetration over time. The white portion refers to the estimated values and the grey to the forecasted.

The plots of approximate findings that forecast the digital divide convergence are presented in Fig. 1. The polynomial function seems to be more pessimistic, as the corresponding plot tends to keep an almost constant distance from zero, whereas the exponential function tends to be closer to the X axis. However, both forecasts imply that European countries will come closer, in terms of broadband diffusion. Thus, based on the exponential model, the homogenization is expected to be met after the 67th quarter, which coincides not before the first quarter of 2018. Of course, this result reflects the current dynamics of the system, based on the level of influence of the factor that affect the process, which leads to huge differentiations in broadband penetration rates among countries.

3 Driving Factors During the Different Stages of Broadband Diffusion: A Non-Parametric Approach and the relationship with income

The contribution of this work is, firstly, to use a non-parametric regression in order to identify the a priori unknown nature of the relation between broadband diffusion (dependent variable) and socio-economic factors (independent variables). Secondly is to assume that the influence of socio-economic factors over broadband diffusion differs during the two main stages of the diffusion process, i.e. before and after inflection point (IP).

The first step corresponds to the determination of the relevant social, economic and other parameters and data collection for each considered country, from Eurostat's database [9]. Then the estimation of the IP of each country based on the non-symmetric Gompertz model according to the following procedure is conducted: Based on the existing diffusion data, for each country, the Gompertz model was trained, using non- linear squares (NLS) [10]. This procedure concluded with the estimation of the diffusion parameters, i.e. the diffusion rate and the saturation level, for each country. Following this, the inflection point is calculated at the 37,79% of the estimated saturation level, as derives from the formulation of the model. Next, the data divided into two groups, based on the estimated inflection point of the diffusion process, for each country, according to the procedure described in the previous step. Diffusion data that have lower values than the inflection point are collected into the first group, while the rest are collected into the second. In addition, there is a third group which consists of the whole dataset which is also analyzed, mainly for comparison reasons. After that, the Sliced Inverse Regression (SIR) algorithm applied to all three groups [11]. This will result into the identification of the most influential parameters and the exclusion of the less relevant ones, leading to dimension reduction with no loss of information. Subsequently, a Kernel smoothing technique was applied, in order to reveal the behavior of the dependent against the independent variables. This will serve as a driver for the construction of the pool of the candidate link functions. Finally, Akaike Information Criterion (AIC) [12] and Bayesian Information Criterion (BIC) [13] were estimated, in order to conclude to the link function that best describes the modeled system, in terms of appropriate statistical measures.

The dataset, that the analysis was based on, consists of cross-sectional, time-series data, over 26 European countries [9]. More specifically, semiannual data were used, starting from the second semester of year 2001 up to December 2009, for all countries. Before the analysis was performed after a dataset transformation, based on the generalized differences [14]. More specifically, the corresponding parameters are: Gross Domestic Product (in €), E-government online availability – Percentage of online availability of 20 basic public services, Tertiary graduates in science and technology per 1 000 of population aged 20-29 years, Persons employed using computers connected to the Internet, Inequality of income distribution – Income quintile share ratio, Proportion of population aged 25-49, School expectancy - Expected years of education over a lifetime, Individuals' level of Computer skills – Percentage of the total number of individuals aged 16 to 74, Individuals' level of Internet skills – Percentage of the total number of individuals aged 16 to 74, Price of telecommunications – Local calls (10 minutes), Communications expenditure as a percentage of GDP and Population Density.

In order to conclude to the link function that better describes the data, the AIC and BIC criteria for the linear and the exponential functions are calculated. According to results, it seems that the exponential model has the lowest values, in both criteria (AIC and BIC). Therefore, it is considered as the most appropriate function to describe the broadband diffusion process in the majority of the cases. As mentioned above, a parametric analysis is also conducted in order to compare the results with those provided by non-parametric method. The comparison was based on appropriate statistical measures such as the coefficient of multiple determinations (R2), the adjusted coefficient of multiple determinations (Ra2), the Residual Sum of Squares (RSS) and the standard error of the estimates (s.e.). Comparison of the results shows that all the statistical measures associated with the non-parametric approach are better, in all cases, than these of the parametric. However, it must be noted that the parametric method provided quite acceptable outputs despite the fact that the non-parametric approach seems to fit the data more accurately.

Based on the assumption that the different stages of diffusion are influenced by different factors, the data used for the analysis were split into two segments, before and after the inflection point of the diffusion process, for each considered country. The analysis revealed that, as initially assumed, the factors that influence diffusion are partially different, during the different stages of the process.

According to the results, it is proved that governmental actions such as E-government online availability and communication expenditures can enhance the process of broadband diffusion. The level of communications expenditures could exert either positive or negative influence depending on the level of cumulative communications investments made in the past. Moreover, the proportion of persons employed using computers connected to the Internet is a driving factor for the proliferation of broadband diffusion for all three groups of considered datasets. It seems that penetration in the private sector is directly and positively related to the broadband diffusion over households. Additionally, population density can be considered as a supporting parameter in the process, as urbanization facilitates the adoption of broadband services.

In the dataset describing the process before the inflection point, Internet skills are added to the influential factors with a positive sign regarding broadband adoption. Thus, policies targeting to motivate people gaining such kind of skills could accelerate broadband diffusion. The results indicate that governmental intervention regardless the level of penetration rate can promote broadband diffusion. It is also concluded that the most suitable regression model can be different based on the maturity level of broadband diffusion.

In addition to the above analysis, a more specific relationship is also examined, i.e. the relationship between broadband diffusion and Gross National Income (GNI) per capita. The aim of this analysis is to provide detailed results regarding the interaction of the two aforementioned variables. To do this, a Granger causality test is applied in a number of countries which where divided into developed and developing [15]. The criterion used for the separation was GNI per capita, based on the classification used by World Bank [16]. The main assumption of this analysis lies on the hypothesis that the relationship between income and broadband diffusion differs depending on the level of the later variable. Therefore, each dataset, i.e. 42 developed and 41 developing countries, examined separately regarding the level of broadband diffusion by using inflection point (IP) in order to split data in two groups, i.e. before and after IP. The estimation of IP of each country based on the non-symmetric Gompertz model [10]. For comparison reason Granger causality test was also applied to the whole dataset, in order to indentify differences in results.

On the one hand, based on the results derived from developed countries, it seems that after IP, broadband penetration causes positive changes in income, while before IP, income will precede positive changes in broadband diffusion. Though, it seems that countries can have economic benefits if they enhance broadband diffusion. On the contrary, countries with low broadband penetration, i.e. before IP, could focus their efforts to provide economic incentives in order to boost broadband demand. It is worth mentioned that results for all the developed countries are similar with those before IP.

On the other hand, the results referring to developing countries reveal that one way relationship is existed between considered variables. More specifically, after IP broadband diffusion can be considered as an accelerator for income increase, while before IP the opposite relationship is forced. As far as the results for all the developing countries, a bidirectional relationship is estimated. According to this, it seems that there is a feedback relationship between GNI per capita and broadband penetration.

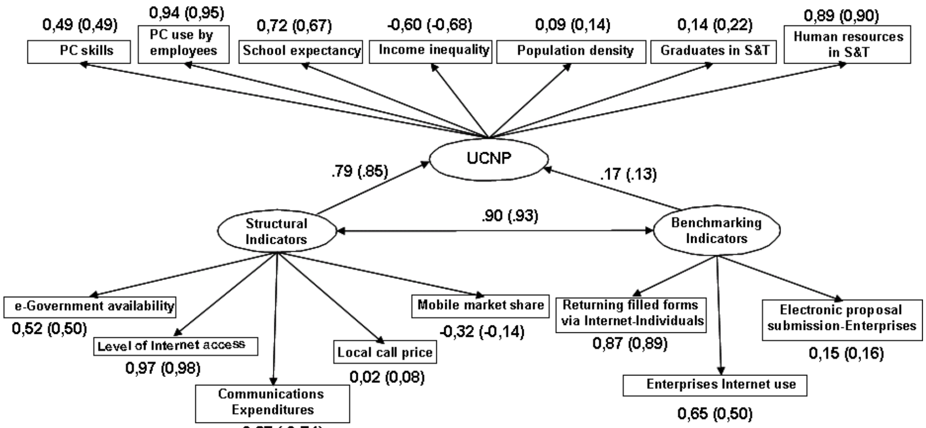
4 Utilization of Communications Network Potential: Public practices and effects

In the context of the present work a new metric, the Utilization of Communications Network Potential (UCNP), which describes the maturity level of what is called "Information Society- IS", is proposed. UCNP is a latent (unobserved) parameter which reflects the output of public and EC applied practices on the use and adoption of new technologies. Public sector indicators are considered as the most appropriate indexes connecting governmental initiatives, policy decisions, EC practices etc., with the enhancement of the UCNP. "Structural indicators" and "Benchmarking indicators: Public services- eGovernment" are the most coherent indexes reflecting the results of public interventions and public e-services, respectively.

The analysis performed in this work is twofold and is based on the preceding considerations. On the one hand, the relationship between UCNP maturity and public sector indicators is studied, under the assumption that these variables interact with each other. On the other hand, the impact of UCNP maturity over the main socio-economic parameters is examined. From the first part of the analysis, useful outputs can be derived, regarding the importance of the two considered key constructs according to public practices. According to the results, policy suggestions and rethinking proposals could arise and new opportunities can be explored by business organizations. The analysis was performed based on a well-known multidimensional methodology, Structural Equation Modeling (SEM), which is employed for the development of the proper model and the estimation of the determinants [17-18].

The analysis is conducted in the European area, among a number of countries for years 2007 and 2009, while dataset were extracted from Eurostat [9]. Year 2007 is the time when the EC stated a more focused strategy regarding the development of UCNP and year 2009 corresponds to the most recent available data. Comparison and analysis of the results between these two years are expected to reveal the progress made, due to the introduced strategies.

The model was validated by a number of goodness- of- fit statistics [19], such as the comparative fit index (CFI), the Tucker-Lewis index (TLI) , and the Root Mean Square Error of Approximation (RMSEA). The results are presented in Fig. 2, where values in parentheses refer to year 2007.



	CFI	TLI	RMSEA
2007	0.944	0.932	0.067
2009	0.921	0.903	0.074

Fig. 2 Estimated standardized regression weights among variables and correlation results; (i)between UCNP and the two main indicators and (ii)between the two main idicators.

According to these results, both indicators have an important influence on UCNP maturity, since they are both positively related with the latent variable of the considered model. More specifically, structural indicators have a greater impact on the maturity level than the benchmarking ones. For this reason, public and EC practices should continue to aim at further expansion of the Internet access. Given the general economic crisis, alternative access technologies, such as mobile which requires lower initial investments, should be considered and included into the developing business plans. Moreover, Communications expenditures are the second dominant factor in this group of indicators. Thus, as the utilization maturity grows, the necessity for corresponding investments will be minimized. This suggests that, despite the fact that Europe considers telecommunications growth to be very important there are still restrictions in terms of the availability of required infrastructures and investments.

In addition, it seems that mobile telephony operators tend to merge in order to achieve a larger market share. However, market concentration has a negative impact on UCNP maturity, as it is commonly related with higher prices and lower quality of services. Though, the development of UCNP maturity seems to boost competition in the mobile market, restraining the market share of the leading operator in this sector. Moreover, it is worth noting that Price does not seem to influence utilization maturity, indicating an inelastic behavior.

On the other hand, e-services show an increase, in terms of their impact on UCNP maturity. Therefore, decisions makers should rethink the content of the offered e-services, as they have to meet the needs of citizens and business organizations.

Additionally, income inequality has an inverse relationship with UCNP maturity level. Thus, the growth of the last-mentioned variable reflects the minimization of the technological exclusion derived from economical reasons. Moreover, educational variables, such as graduates in S&T and School expectancy could be enhanced by the utilization maturity level. Finally, factors describing the working environment, such as the required qualifications –Computer Skills, Computer Use etc- and the market share of Science and Technology sector in terms of the percentage of the labor force, are heavily influenced by UCNP maturity level.

5 Assessment of Information and Communications Technology maturity level

This work aims to express the level of ICT development in each country, through an adequate conceptual model. To do this, a latent variable is defined, the ICT maturity level, in the context of Structural Equation Modeling (SEM) [17-18]. The ICT maturity level is determined by three elements (sub-indices), “Access”, “Use” and “Skills”, which are also latent variables and which in turn are described by observed factors. These factors are indicators which derive by the countries’ statistical data. Since the estimation of ICT evolution by the means of an appropriate metric is important, the ICT Maturity Level Index (IMLI) is introduced, to improve the ICT Development Index (IDI) proposed by the ITU [20]. Structural equation modeling allows for the precise estimation of the sub-indices and indicators’ weights, which are different from those set by ITU, especially when applied to developing countries. Calculation of the IMLI was based on statistics from 159 countries [16]. Due to their huge differences in the corresponding economic wealth, the considered countries were grouped according to their income level, as expressed by the GNI per capita, in order to avoid bias in estimations. The common approach to do this is the clustering of countries into developed and developing. This separation, proposed in the present work, proved very important according to the results.

It could be probably expected that the impact of sub-indices and their indicators over the ICT maturity level would change slowly over time. However, within short periods of time, significant changes are observed on indicators statistics describing "Access", "Use" and "Skills" led to the examination of their dynamic nature. Therefore, the analysis was performed for two consecutive years, revealing marginal changes regarding the sub-indices but significant for their indicators. Thus, a different ranking of the countries with respect to IMLI, from year to year, was apparently obtained. In this way, the time behavior of the model was highlighted.

The first hypothesis of the proposed model is that there is a link between GNI per capita and IMLI. The second hypothesis is that IMLI is related with "Access", "Use" and "Skills" respectively. According to the above hypotheses, the new entity that evaluates the ICT Maturity Level (IML), is described by the following Eq.2:

$$IML = w_{Access} * Access + w_{Use} * Use + w_{Skills} * Skills \tag{2}$$

where the considered sub-indices ("Access", "Use" and "Skills") participate with a corresponding weight (w_{Access}, w_{Use} and w_{Skills}). The sub-indices are described by a number of observed indicators. Following the above consideration the estimation of IMLI is based on Eq.3:

$$\begin{aligned} IMLI = {} & w_{Access} * (w_{A1} * A1 + w_{A2} * A2 + w_{A3} * A3 + w_{A4} * A4 + w_{A5} * A5) + \\ & w_{Use} * (w_{U1} * U1 + w_{U2} * U2 + w_{U3} * U3) + w_{Skills} * (w_{S1} * S1 + w_{S2} * S2 + w_{S3} * S3) \end{aligned} \tag{3}$$

In the above expression of IMLI, Ai, Ui and Si are the corresponding observed variables, for each country, while w_{Access}, w_{Use}, w_{Skills}, $w_{A,i}$, $w_{U,i}$ and $w_{S,i}$ are the estimated weights resulting from SEM approach. The implementation of the proposed model was performed by using Ordinary Least Squares (OLS).

Following the methodology described above, the corresponding weights for the sub-indices w_{Access}, w_{Use} and w_{Skills}, as well for the indicators w_{Ai}, i=1,2,..5, w_{Ui}, i=1,2,3, and w_{Si}, i=1,2,3, can be estimated using the SEM approach. Based on these weights, the index IMLI can be calculated for each country, according to Eq.3, assuming that within the same cluster they do not vary significantly among the countries. The above weights were calculated using two different datasets, one formed by the data of the 75 developed countries and the other formed by the data of the 84 developing countries.

According to the results, income level has a significant effect on ICT development, which is more intense for countries with low incomes. Furthermore, it is important to notice that the estimated weights of the three sub-indices of the model have quite different values between the developed and the developing countries. "Access" turned out to be the dominant component regarding IML for both groups of countries. These findings indicate that access availability has a substantial influence on ICT development. More specifically, access speed in developed countries is the most important indicator affecting IML. On the contrary, in developing countries the impact of telephone lines on IML reflects the lack of the required infrastructures.

The “Use” element is significantly more important for developed countries than for developing. In particular, fixed broadband connections are the dominant indicator for further ICT growth. Not surprisingly, the importance of “Skills” is lower in developed countries, indicating the sufficient educational level they have reached. On the other hand, in developing countries “Skills” exert great influence on IML. Hence, it is proved that educational level is directly related to the ICT development. Therefore targeted actions should take place, especially in developing countries, where even nowadays literacy rates remain in extremely low levels.

Europe is the leading area, in terms of ICT development, as the great majority of the countries belonging to the first 20 places in world ranking are European. This conclusion is in line with ITU [20], indicating that ICT uptake in Europe is faster than in other areas, probably due to common regulatory framework and orchestrated policies implemented in all countries. There is an observable improvement each year with respect to ICT development, especially for the developed countries. Further, best practices could be analyzed and adapted to other countries’ increasing ICT diffusion.

6 Conclusions

The contribution of this dissertation lies in the results of the above studies. Initially, an index for the assessment of digital divide convergence in terms of broadband penetration is proposed which in turn it can be used as a reliable tool in order to forecast the progress made in the aforementioned convergence process. Next, the evaluation of a number o socio-economic factors affecting broadband penetration in relation to the diffusion level took place. It turned out that before inflection point, e-Government on line service availability is the dominant factor for further broadband diffusion. On the contrary, after inflection point, working environment, and specifically, persons employed using computers connecting to the Internet, fosters broadband adoption. After that, the relation between GNP per capita and broadband diffusion is examined by applying a causality test. It is proved that the above relation depends on the level of broadband penetration. More specifically, before inflection point GNI per capita can cause positive change in broadband penetration, while after inflection point broadband diffusion can cause an increase in income.

Subsequently a new metric, the “Utilization of Communications Network potential –UCNP), is determined to evaluate the effectiveness of public practices aiming to enhance ICTs. According to results, it seems that UCNP is affected more by structural indicators then benchmarking indicators. Finally, ICT maturity level is estimated based on “ICT Maturity Level Index- IMLI” in accordance to “ICT Development Index-IDI”, proposed by ITU. The estimation is made with precision and according to results, the influence of sub-indices “Access”, “Use” and “Skills” and their corresponding variables, differs between developed and developing countries.

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