A digital divide convergence rate estimation methodology

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Abstract—**A new methodology for the estimation of the digital divide convergence is proposed, together with an alternative approach for diffusion forecasting. The methodology is based on the deviation between the country that exposes the biggest penetration of the service considered and the follower countries. This deviation is calculated and expressed against time, revealing a decreasing pattern which is in turn approximated by linear, exponential, logarithmic and polynomial functions. As a result, the time of convergence of the digital divide can be forecasted, together with the expected diffusion levels across countries. The data used correspond to diffusion of broadband services across the wider European area. Evaluation of the methodology provided quite accurate estimators of the convergence process and rational forecasts regarding the time of convergence. Extensions of the proposed methodology, towards the direction of accuracy of estimation, are provided at the final section of the paper.**

Index Terms— **digital divide convergence, broadband services, diffusion, forecasting**

I. Introduction

DIGITAL divide among countries has gained a superior place in political agendas. Measurement of the digital divide gap was widely considered in the relevant literature [1]-[5], where access to new technologies, both in terms of technical infrastructure and basic IT skills, is studied. Infrastructure and IT skills constitute the necessary prerequisite for broadband penetration, the main consideration of this work.

Worldwide initiatives focusing on broadband enhancements have taken place, targeting in the acceleration of broadband penetration [6]. Despite the increasing rates of broadband diffusion, the digital divide gap between countries is still evidence, being outstandingly wide in some cases in terms of diffusion rates, connection speeds and prices. Informative studies regarding the factors affecting the existence and widening of the digital divide gap can be found, among others, in [7]- [9]. Analysis of relevant frameworks revealed that the ICT infrastructure and usage, together with the costs and availability of online public services are the inhibitory factors related with the convergence of the digital divide. Elimination of these factors is expected to lead to convergence, in terms of the digital divide gap.

Towards this direction, the present work focuses on the development of a methodology for estimating the rate of convergence of the digital divide among countries. The methodology is based on the estimation of the declination rate of the deviation between the country with the highest penetration in broadband services and the rest considered countries. The application of the methodology is not limited to the broadband services only, but it can also be applied over any other high technology service. An important aspect of the proposed methodology is the ability to forecast the time of fully convergence, based on the recorded levels of broadband diffusion. It should be noted that the present methodology does not attempt to perform an analysis to identify the factors that are responsible for the digital divide but it presents an estimation of the rate of digital convergence, as a consequence of the influence of the underlying factors.

Evaluation of the proposed methodology was based on data describing broadband diffusion across 31 countries from the wider European area [10]. The available historical data describe broadband penetration over households per quarter-term, from September 2001 to June 2007. The broadband services considered are DSL, Fiber To The Building (FTTB) and cable connections.

The rest of the paper is as follows: Section II presents the proposed methodology, whereas Section III analyses its evaluation over the available data. Finally, conclusions and proposals for extensions of the methodology are presented in Section IV.

II. Methodology

According to Rogers [11], a deterministic approach of diffussion theory suggests that digital convergence is practically a matter of time. Traditional approaches for the estimation of the digital divide are usually based on social, economical and technological parameters, as well as indices that count income, education etc [1], [12].

The proposed methodology is not based on these parameters explicitly but it rather reflects their impact on the observed broadband penetration. This is expressed by calculating the rate of convergence of the deviation of the diffusion between the leading country, in terms of broadband penetration, and the following countries.

More specifically, the methodology consists of the following steps, which are performed for each quarter term of

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- Historical data were sorted in decreasing order according to *rank-size rule* [13]. Rank-size rule refers to the sorting for the participating countries in the order derived by the following algorithm: The country with the highest broadband penetration, over a specific quarter-term period is set to have rank equal to 1, the second country is set to have rank equal to 2 etc. In that way broadband penetration rate is not explicitly related to specific countries but rather on their relative positions, as these are defined by the corresponding broadband diffusion level.
- Data are normalized and expressed as a percentage of penetration of the leading. Thus, the leading country has a value equal to 1, whereas the following countries have values that all together constitute a decreasing series.
- The deviations are calculated. Deviations are defined as the distance between the penetration ranked to be equal to 1 (highest) and the rest of the recorded penetrations.
- The resulting time series of the calculated deviations is plotted against time (quarter-term).
- Results are approximated by a suitable function, so that the recorded process can be estimated and its future values can be forecasted.

The above algorithm is applied over the European broadband historical data and is presented in the following section.

III. Evaluation of Methodology

The methodology for the estimation of the digital divide convergence was evaluated over the dataset which describes broadband penetration across European countries, as described in the introductory section.

More specifically and according to the latest available record for broadband diffusion, which refers to the second quarter-term of 2007, the average value for broadband diffusion of the participating countries is calculated. Based on that average, the available dataset is divided into two segments. The first one includes the countries where broadband penetration is above average, whereas the second one consists of the rest countries where penetration is bellow the calculated average. In this way, a number of 17 countries belong to the first subset and the rest 14 countries constitute the second segment. The main assumption on which this segmentation is based upon is that countries with high penetration rate (above average) are the ones that have already developed mature broadband markets. On the contrary, the rest of the countries (bellow average) are moving towards their early steps of broadband evolution, therefore it is quite early for accurate future predictions in their corresponding diffusion progress. For this reason, evaluation of the proposed methodology is performed only over the first set of the 17 countries.

Calculation of the deviation and application of the algorithm described in the previous section resulted in the diagram presented in Fig. 1. The calculated deviations refer to the circles in Fig. 1, under the label “Actual”. Convergence of the digital divide is the obvious outcome of the inspection of the graph. As deviations’ time series is expressed against the quarter they refer to, the horizontal axis indicates the number of quarters, whereas the vertical axis represents deviations values. The first quarter of the dataset corresponds to September of 2001 and the last one to June 2007.

According to the proposed methodology, the next step of the algorithm refers to the approximation of the digital divide process, for estimation and forecasting purposes.

For this reason, a number of mathematical functions were employed and the after the pertinent analysis the following families of models turned out to be more suitable to describe the process:

$$L = a+b*X$$
$$E = \exp(a+b*X)$$
$$P = 1/(a+b*X)$$
$$Ln = \ln(a+b*X)$$

Results’ accuracy, for each model evaluated, was based on the calculated R-square and Mean Square Error (MSE). The threshold for the results to be accepted was set to 94%, as far as the R-square is concerned. R-square and MSE calculation results for the first segment of the 17 European countries are presented in Table I:

TABLE I
R-SQURE AND MSE RESULTS

Model	R-square	MSE
Linear	98.13%	0.0029
Exponential	97.89%	0.0032
Polynomial	96.43%	0.0054
Logarithmic	94.67%	0.0081

The plot of the approximation results for each participating model is presented in Fig. 1. As observed, all of the models employed provided quite good results, though different as far as forecasted time of convergence is concerned.

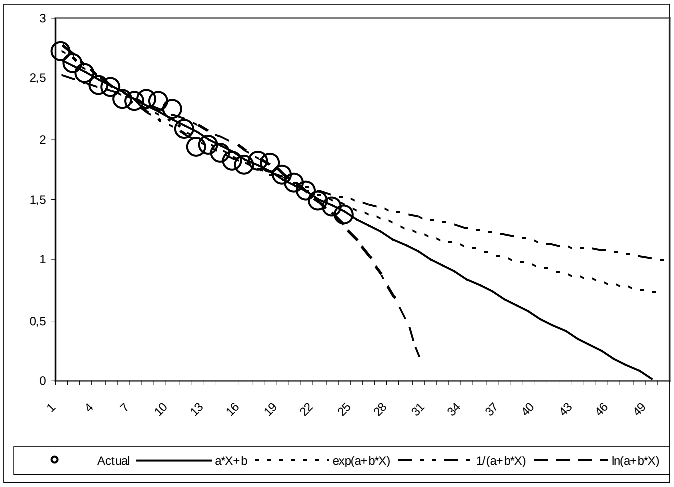

Fig. 1 Results from linear, exponential, polynomial and logarithmic fitting for countries with broadband penetration above average.

Further analysis of the results obtained from the evaluation of the methodology concludes that the linear model provides the highest R-square, with the smallest MSE at the same time. Therefore, it is considered as the most appropriate for describing the process of convergence of digital divide for the countries considered and for the corresponding time period (September 2001 to June 2007).

Based on the above results, the 17 European countries of the first segment considered, are expected to meet digital convergence at about the 49th quarter-term, from the beginning of observation, which coincides with June 2013. As linear regression gives a quite optimistic approach, the actual convergence rate is expected to follow a combination between the linear and an exponential path. On the contrary, logarithmic and polynomial models can be rejected as they provide nonrealistic and quite optimistic forecasts, in terms of time of convergence. The visual representation of the above analysis of models' results can be also observed in the plots of Fig. 1.

As far as the second subset of the rest 14 countries is concerned, the estimation of the digital divide convergence, by employing the same families of models, gives R-square and MSE which are presented in Table II:

TABLE II
R-SQURE AND MSE RESULTS

Model	R-square	MSE
Linear	91.66%	0.015
Exponential	88.15%	0.021
Polynomial	84.45%	0.028
Logarithmic	98.47%	0.0027

A visual representation of the above results is given by the graphs provided in Fig. 2. In this case, the logarithmic function seems to provide better fitting results, however it cannot give a reliable prediction for future progress. This, as mentioned before, happens because broadband markets of the corresponding countries are in their early stages and there are still many fluctuations to their diffusion shapes. Moreover, if the linear function is used again for estimation and forecasting, digital divide convergence for these countries is probable to be met after the 63rd quarter-term from September 2001, which is in about year 2017, as shown in Fig. 2:

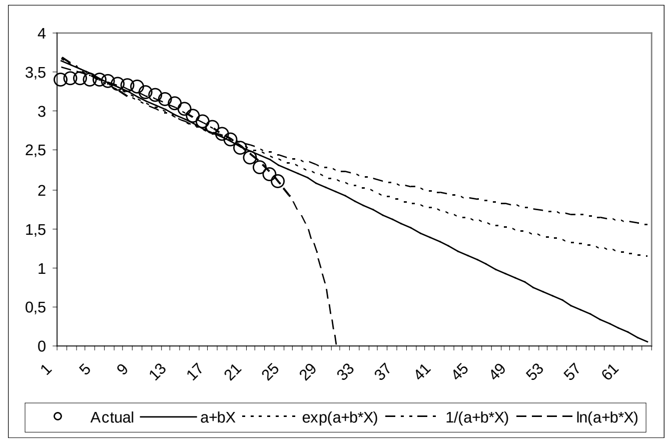

Fig. 2 Results from linear, exponential, polynomial and logarithmic fitting for countries with broadband penetration bellow average.

IV. CONCLUSIONS

A methodology for estimating the digital divide convergence rate is presented and evaluated in the present work. The methodology is built upon the calculation of the rate of convergence of the deviations between the leading country, the country having the higher level of broadband diffusion and the following ones. Thus, decrement of the calculated deviation is synonymous to the closing of the digital divide gap. In order to estimate the process of convergence, four families of models were used to functionally approximate the values of deviations against time. Among them, the linear model turned out to describe the process more accurately. Application of the methodology revealed that the 17 most mature broadband countries' markets are expected to fully converge at about year 2013.

The importance of the methodology is that it does not depend explicitly on the absolute values of the countries broadband diffusion but rather on their relative order, according to the rank-size rule. Thus, the deviations are calculated against the leader country, which may not be the same at each quarter. The methodology studies the movement of the group of countries, as a whole, to digital convergence, in a way that it is not explicitly related to diffusion increment. The findings of the presented framework are in accordance with the results of previous studies using the traditional approaches, as in [8], [9], where a movement towards convergence is revealed, based on corresponding methodologies.

Extensions of the proposed methodology include the study of the process of digital convergence into a micro level, instead of the macro level which was presented in this work. Towards this direction, the impact of each country's penetration rate to the total convergence process should be included and the way it affects the total process of convergence. This is possible to be achieved by constructing a new estimation methodology together with pertinent concentration indices for broadband diffusion in the European area.

Appendix

Countries taken into consideration, in decreasing order, according to broadband penetration in June 2007.

TABLE III
COUNTRIES' RANKING

Rank	Country	Rank	Country
1	Iceland	17	Spain
2	Denmark	18	Estonia
3	Netherlands	19	Lithuania
4	Norway	20	Hungary
5	Finland	21	Czech Republic
6	Sweden	22	Latvia
7	Switzerland	23	Poland
8	Belgium	24	Romania
9	France	25	Croatia
10	United Kingdom	26	Greece
11	Slovenia	27	Slovakia
12	Ireland	28	Bulgaria
13	Austria	29	Serbia
14	Germany	30	Ukraine
15	Italy	31	Montenegro
16	Portugal		

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