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Impact of cross-national diffusion process in telecommunications demand forecasting

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Abstract New product diffusion process studies focus mainly on estimating the adoption rate of the product, within the boundaries of the targeted market. However, and especially for high technology and telecommunications products, it is very likely the case that products or services are introduced simultaneously into a number of market segments, a fact that it is rarely taken into account. Thus, the effect of market and population interaction, and the consequent co-influence in the diffusion rates is not considered. This work focuses on developing and evaluating a pertinent methodology, so as to capture this cross-national interaction influence in the diffusion process.

Keywords Diffusion · Cross-national influence · Cross-area influence · Forecasting · Telecommunications

1 Introduction

Since the analysis of the growth rate of new products was first carried out, a substantial body of research looking into targeted markets and areas [1], such as the telecommunication sector [2], has been undertaken. However, the main focus was limited to the areas, to the corresponding populations of these markets, and to the factors affecting the diffusion process, without considering the case that the same product is simultaneously introduced in two, or more, markets in neighboring areas. In this case, the factor of population interaction, which may affect the diffusion shapes, is disregarded. This is the case of telecommunication products and services, where a new technology is quite possible to be introduced in more than one market, each one having its own economic and cultural characteristics.

Whenever such a new telecommunication product is introduced at the same time in a number of areas, such as countries, the corresponding diffusion processes are expected to reveal differences in their shapes. This is due to the underlying differences of the considered markets which can be related to introduction prices [1], household incomes [3], product advertising, marketing strategies, or other characteristics of the target population and areas [4].

The main reason for these considerations is that nowadays people from various countries, or areas in the same country, interact with each other, thus being influenced [5]. This influence affects the diffusion progress of many products, telecommunication products in particular. For this reason, the study of a "cross-national" product's diffusion process, should take under consideration the "cross-area" influence, described above. This work focuses on developing a framework and a corresponding methodology to accommodate the interaction and influence in the diffusion shapes described above. An aggregate diffusion model is then developed, to estimate the amount of influence, in each direction.

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2 Previous research

Despite the fact that cross-national diffusion turned out to be an important and interesting field of research, especially for market managers dealing with international markets, not much of work has the literature to present. As summarized in [6], Gatignon, Eliashberg and Robertson [5], Takada and Jain [7], and Helsen, Jedidi and DeSarbo [8] have some significant work to present, in studying the cross-national diffusion process. Their results can be summarized in the following:

1. New product's diffusion process is based mainly on the market's culture, and differences in penetration are explained by factors describing the specific country, such as mobility, cosmopolitanism, percentage of employed women etc.
2. The later a product is introduced in a country's market, the faster the expected adoption rate. A "lead-lag" influence exists that explains the fast adoption rate in the lag country. This refers to the so called "time-lag" influence.
3. Market segments, based on the diffusion parameters, are not constant. Instead they are dependent on the nature of the considered product, each time.

3 Diffusion models

Diffusion models are mathematical functions of time, used to estimate the parameters of the diffusion process of a product's life cycle at an aggregate level, without taking in consideration the underlying specific parameters that drive the process.

The most well-known representatives of the models developed for diffusion estimation, are the Bass model [9], Fisher–Pry model [10], logistic family models [11], as well as the Gompertz model [12, 13]. Logistic models and variations of the Gompertz model provide S-shaped curves which are used in common in forecasting diffusion of products or services. These models are used to describe and forecast demand and diffusion at the aggregate level, which is the total market response rather than at the individual customer level (this approach is described by the so called choice-based models focusing on the probability of individuals to adopt the innovation whose market behaviour is driven by maximization of preferences, as modern economic choice theory assumes). S-shaped patterns usually derive from the differential equation

$$\frac{dY(t)}{dt} = \delta * Y(t) * [S - Y(t)]. \tag{1}$$

In (1), $Y(t)$ represents total penetration at time t, S the saturation level of the specific technology and δ is a constant of proportionality, the so-called coefficient of diffusion. Penetration is defined as the proportion of the population that uses the product or service being examined.

At the time that the particular technology is introduced ($t = 0$), there is a critical mass, met in literature as the "*innovators*", that initially adopt it. This number influences the rate of diffusion and the time of saturation is met.

In the context of this work, the Linear Logistic Model is used, after necessary development in order to accommodate the cross-area influence.

The general form of the logistic models family is:

$$Y(t) = \frac{S}{1 + e^{f(t)}}, \tag{2}$$

where $Y(t)$ is the estimated diffusion level and S the saturation level. $f(t)$ is given by the following formula:

$$f(t) = -a - b * t(m, k). \tag{3}$$

In the above equation $t(m, k)$ is a non-linear function of time (except the linear logistic model, where $t(m, k) = t$) and is described by a number of different formulations, according to the model's construction.

The variable a is a location or "timing" variable [15]. It is responsible for moving the diffusion function forwards or backwards, without otherwise affecting the shape of the diffusion function. For example, when a has a high value, it can be considered that the studied innovation is very "advanced" in its adoption rate, at time t.

The variable b that participates in the same equation, is a measure of the diffusion growth, in the sense that it is the coefficient of proportionality of the growth rate in the number of adopters at time t, relative to the fraction of adopters that have not yet adopted at time t. This can be verified by differentiating (3), with respect to t, which proves that the number of new adopters at time t, relative to the fraction of adopters that have not yet adopted at the same time, is a linear function of the total number of consumers that have already adopted at time t. This is presented in (4)

$$\frac{dY_t}{dt} = b * Y_t * \left(1 - \frac{Y_t}{S}\right). \tag{4}$$

The linear instance of the model is given by

$$t(m, k) = t. \tag{5}$$

The linear logistic model is also known as Fisher–Pry model.

4 Development of the proposed model

If the case of simultaneous effect among the diffusion processes of a new product in two countries is considered, then, in order to capture the effect of diffusion in one country on diffusion in the other, the diffusion in each country is modeled as [17]:

$$\frac{dF_i(t)}{dt} = \delta_i * F_i(t) * [S_i - F_i(t)] * x_i(t), \tag{6}$$

where $F_i(t)$ is the cumulative penetration at time t and $x_i(t)$ is the current marketing effort term which should include only those effects that are happening at time t and influence the adoption rate. In order to model the impact of diffusion of the second country on the first country's diffusion, $x_i(t)$ is modeled as [16]:

$$x_2(t) = 1 + (b_{21} * \text{ change at time } t \text{ in diffusion rate of 2nd country}). \tag{7}$$

In (7), 1 represents the natural time, the diffusion force is simply the cumulative adoption up to t, and b_{21} measures the impact of Country 2's diffusion on Country 1's diffusion. This can be represented by:

$$x_2(t) = 1 + \left(b_{21} * \frac{dF_2(t)}{dt}\right).$$

By considering the same differential equation for the other country, the following set of equations is derived:

$$F_1(t) = S_1 * \frac{1}{1 + e^{-a_1 - b_1 * (t + b_{21} F_2(t))}}, \tag{8}$$

$$F_2(t) = S_2 * \frac{1}{1 + e^{-a_2 - b_2 * (t + b_{12} F_1(t))}}. \tag{9}$$

Variables a and b are used in the same sense as in the logistic diffusion model described above, in (3).

The set of (8) and (9) are solved simultaneously, in an iterative way, by following the next steps [17]:

1. Assign a value of 0 to $F_1(t)$, $F_2(t)$ on the right-hand side of (7) and (8).
2. Estimate a_i, b_i, S_i of the two resulting equations. Call them $(a_1, b_1, S_1, a_2, b_2, S_2)_0$.
3. Using $(a_i, b_i, S_i)_0$ and using 0 for F_1 and F_2 on the right-hand sides, evaluate $F_1(t)$, $F_2(t)$ of (7) and (8). Call these $(F_1(t), F_2(t))_1$.
4. Assign $(F_1(t), F_2(t))_0$ to the $F_1(t)$ and $F_2(t)$ on the right-hand side of (7) and (8) and estimate a_1, b_1, S_1, b_{21}, a_2, b_2, S_2, b_{12}. Call them $(a_1, b_1, S_1, b_{21}, a_2, b_2, S_2, b_{12})_1$.
5. Using $(a_1, b_1, S_1, b_{21}, a_2, b_2, S_2, b_{12})_1$ and using $(F_1(t), F_2(t))_1$ for $F_1(t)$ and $F_2(t)$ on the right-hand sides, evaluate $F_1(t)$, $F_2(t)$ of (7) and (8). Call these $(F_1(t), F_2(t))_2$.
6. Assign $(F_1(t), F_2(t))_2$ to $F_1(t)$, $F_2(t)$ on the right-hand side of (7) and (8) and estimate $(a_1, b_1, S_1, b_{21}, a_2, b_2, S_2, b_{12})_1$ of the two resulting equations. Call them $(a_1, b_1, S_1, b_{21}, a_2, b_2, S_2, b_{12})_2$.
7. Repeat Steps 5 and 6 until no changes in the estimates of a_1, b_1, S_1, b_{21}, a_2, b_2, S_2, b_{12} are found.

The above procedure is implemented by using a genetic algorithms approach. The objective function for the algorithm was the minimization of the squares of the errors, between the actual and the estimated values of penetration.

5 Evaluation of the proposed methodology

This section is devoted in the evaluation of the so far proposed methodology, over mobile phone and broadband diffusion data, over different cases of evaluated areas. The corresponding results are presented and discussed.

5.1 Eastern–Western Europe

In this section the influence between Eastern and Western Europe, regarding diffusion of mobile phones, is considered. Table 1 presents the actual diffusion data (mobile phones over corresponding populations) for both areas, as these were recorded by Eurostat. In Table 2, the estimated

Table 1 Diffusion of mobile phones over population, Eastern–Western Europe (actual data) (source: Eurostat [14])

Year	Eastern Europe $F_1(t)$	Western Europe $F_2(t)$
1999	0.0385	0.4367
2000	0.0759	0.6864
2001	0.1353	0.8173
2002	0.2057	0.8712
2003	0.2992	0.9414
2004	0.3971	1.0032
2005	0.4565	1.0362

Table 2 Initial estimation of parameters

	Eastern Europe	Western Europe
S	0.560258	1.025588
a	−3.22	−0.93592
b	0.676114	0.740675

Table 3 Final estimation of parameters

	Eastern Europe	Western Europe
S	0.5802	1.025588
a	−3.22	−0.93592
b	0.676114	0.740675
	$b_{21} = 0.0155$	$b_{12} = 0.0000$

values of the diffusion parameters are presented, before the application of the proposed methodology (initial estimates). These estimates were derived by applying the linear case of the logistic model, as described by (2) and (5). The corresponding final estimates, based on the derived (8) and (9), are presented in Table 3, together with the estimated values regarding the influential impact of one area over the other. More specifically, the b_{21} parameter is the final estimation of the influence of Western over Eastern Europe and b_{12} is the opposite case. The physical meaning of the latter parameters (b_{12} and b_{21}) can be perceived as an increment to the initially estimated diffusion, due to the cross area influence. In that sense, the initially estimated diffusion rate for Eastern Europe is expected to be adjusted by b_{21} times after the application of the methodology.

The direct observations of this case's results are that Eastern Europe is expected to be influenced by Western Europe and not vice-versa. Figure 1 depicts this influence and the corresponding change in the diffusion process, by revealing the corresponding adjustments to the initially estimated parameters, whereas Fig. 2 shows the unchanged shape in Western Europe's diffusion. Moreover, Western Europe's influence speeds up diffusion in Eastern Europe, in the sense that the saturation level of penetration is met earlier in time than initially estimated. On the other hand, the value of saturation level remains unchanged, only the diffusion speed for meeting this saturation level is affected. The observed results are coherent with what someone would expect, as Western Europe's countries, like Germany or Sweden, where adoption rates in technology products are remarkably high, have a higher technological level to present than that of Eastern Europe's. This can also be verified by the corresponding values of the variables α and b, which were described in the preceding sections.

In addition, Western Europe's countries have a higher mean GDP and GDP per capita, than the corresponding values for Eastern Europe's countries. Figure 3 depicts the

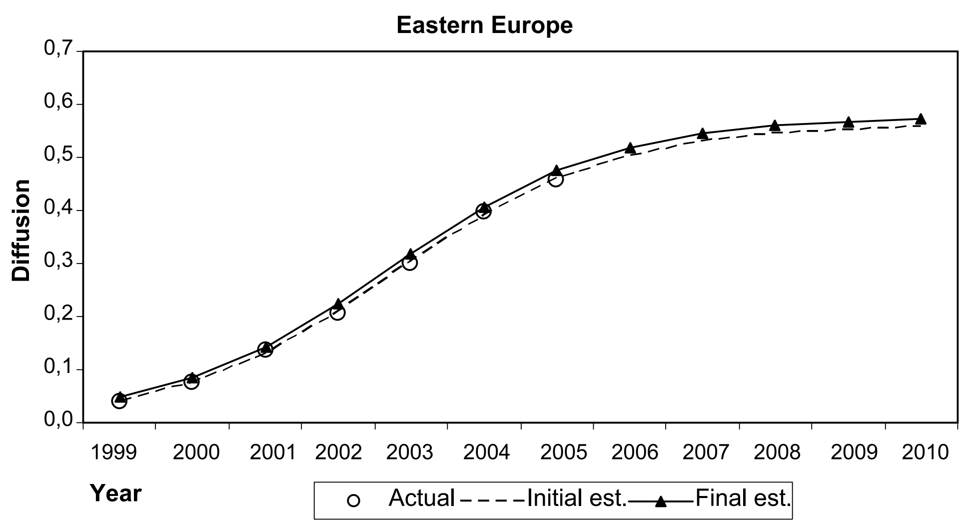

Fig. 1 Cross-national diffusion results, Eastern Europe

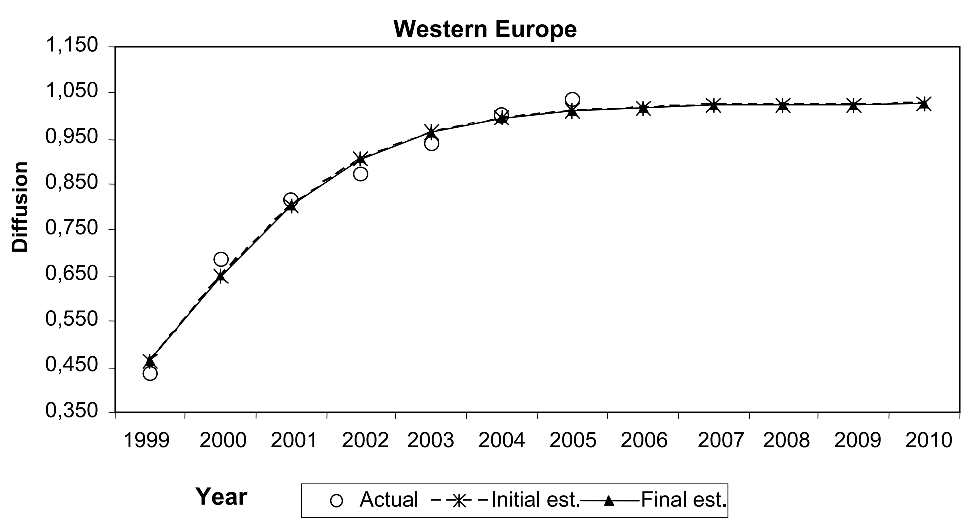

Fig. 2 Cross-national diffusion results, Western Europe

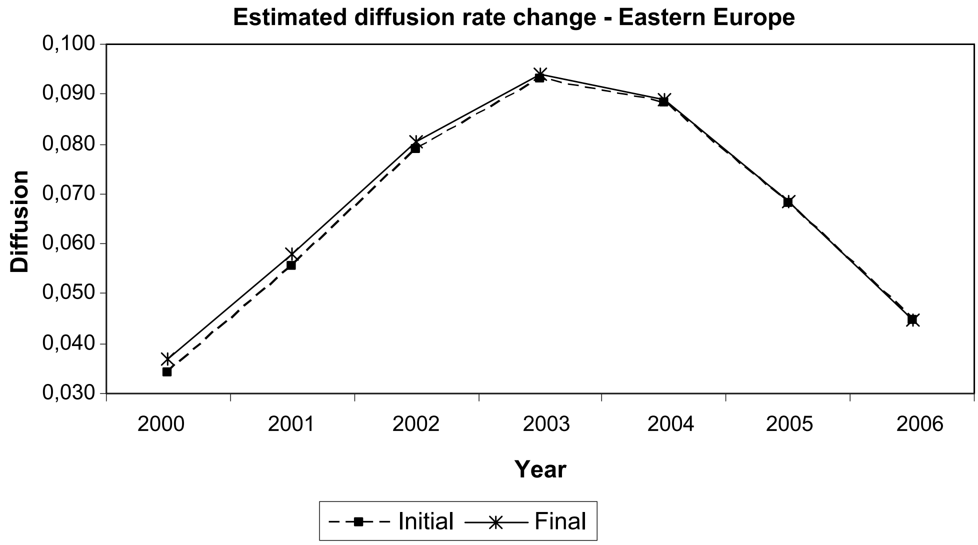

Fig. 3 Change in estimated diffusion rate due to cross-national influence, Eastern Europe

Table 4 Adjusted diffusion estimation after cross-national methodology application (source: Eurostat [14])

Year	Eastern Europe	Western Europe
1999	0.0415	0.4628
2000	0.0759	0.6492
2001	0.1317	0.8035
2002	0.2108	0.9061
2003	0.3040	0.9649
2004	0.3924	0.9957
2005	0.4606	1.0111
2006	0.5053	1.0186
2007	0.5316	1.0222
2008	0.5460	1.0240
2009	0.5537	1.0248
2010	0.5576	1.0252

change in the diffusion rate of mobile telephony in Eastern Europe before and after the application of the methodology.

5.2 Latin–North America

The cross area influence between Latin and North America is evaluated in this case, over the dataset that describes mobile phones diffusion. Following the previous section, the tables in this section provide the same information. More specifically, Table 5 contains the actual data for both areas, as they were collected from Eurostat's database. In Tables 6 and 7 the initial and final estimations of the parameters are presented. Finally, Table 8 contains the adjusted estimation and forecasted values regarding diffusion of mobile phones in the areas under examination.

Table 5 Diffusion of mobile phones over population, Latin–North America (actual data) (source: Eurostat [14])

Year	Latin America $F_1(t)$	North America $F_2(t)$
1999	0.0902	0.33
2000	0.1375	0.4048
2001	0.1804	0.4862
2002	0.2112	0.4917
2003	0.2574	0.5863
2004	0.3102	0.5918
2005	0.3542	0.6347

Table 6 Initial estimation of parameters

	Latin America	North America
S	0.51706	0.692874
a	−1.80652	−0.45926
b	0.367356	0.393623

Table 7 Final estimation of parameters

	Latin America	North America
S	0.53170	0.692874
a	−1.80652	−0.45926
b	0.367356	0.393623
	$b_{21} = 0.00013$	$b_{12} = 0.0000$

Inspection of the results presented above, reveals that North America influences Latin America by a factor of $b_{21} = 0.00013$. The physical meaning of the parameter b_{21}, is that each year's adoption rate in Latin America, is ex-

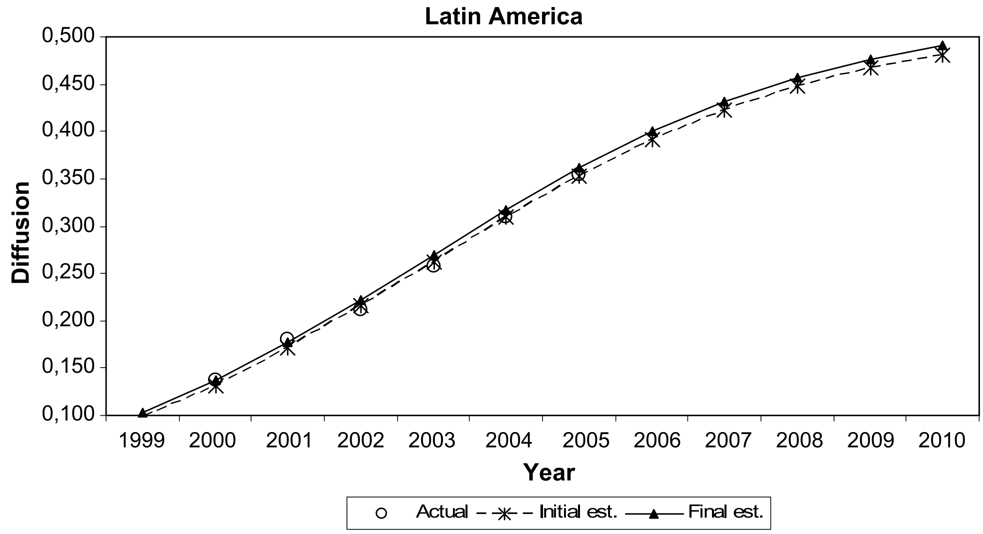

Fig. 4 Cross-national diffusion results, Latin America

Table 8 Adjusted diffusion estimation after cross-national methodology application

Year	Latin America $F_1(t)$	North America $F_2(t)$
1999	0.0991	0.3350
2000	0.1319	0.4027
2001	0.1711	0.4662
2002	0.2154	0.5218
2003	0.2625	0.5673
2004	0.3093	0.6029
2005	0.3529	0.6295
2006	0.3911	0.6488
2007	0.4228	0.6625
2008	0.4479	0.6721
2009	0.4671	0.6787
2010	0.4814	0.6832

pected to be adjusted by 0.00013 times the diffusion rate of North America, for the same year. This can be considered as a corresponding number of additional adopters, as compared to the initially estimated diffusion values, which in turn can be translated to a corresponding number of additional expected sales.

On the other hand, North America's diffusion shape is not influenced at all. This is in accordance with the expected outcomes, as North America has a higher technological maturity, than Latin America, as USA and Canada's industrialization level cannot be compared with Latin America's countries. Mean household incomes are also quite different between populations of the areas considered.

Table 9 Diffusion of ISDN connections, Greece–Italy (actual data) (source: OECD)

Year	Greece $F_1(t)$	Italy $F_2(t)$
1996	0.0001	0.0019
1997	0.0001	0.0050
1998	0.0004	0.0113
1999	0.0027	0.0438
2000	0.0092	0.0796
2001	0.0189	0.0934
2002	0.0261	0.1018
2003	0.0293	0.1021

5.3 Greece–Italy

In this last examined case the ISDN technology is evaluated, over two European countries, Greece and Italy. The data presented in Table 9 were collected from OECD, and describe diffusion of ISDN connections over the corresponding populations of the two countries. In addition, Table 10, Table 11 provide the values for the initial and final estimations. Finally, Table 12 presents the adjusted values for diffusion that were derived after the application of the methodology.

As clearly shown, by both numerical and graphical results, Italy turns out to influence Greece, than vice-versa, and this could be explained due to the higher technological adoption status of the Italians, than this of the Greeks. Figures 6 and 7 present the graphical results for each country, where the adjustment to Greece's initially estimated diffusion rate can be observed, whereas the negligible impact of Greece's diffusion leaves Italy's adoption rate practically unchanged.

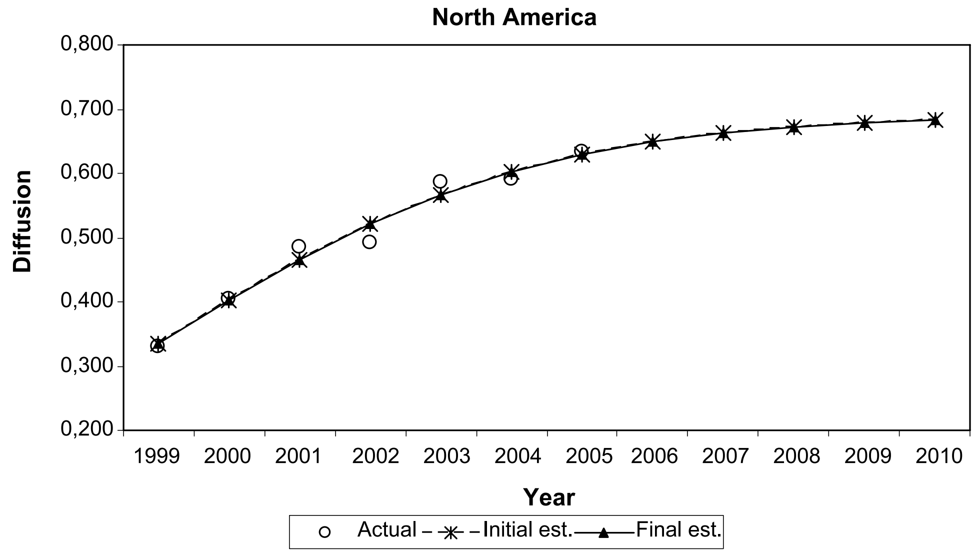

Fig. 5 Cross-national diffusion results, North America

Table 10 Initial estimations

	Greece	Italy
S	0.030228	0.101844
a	−13.3714	−12.7713
b	1.389228	1.557124

Table 11 Final estimations

	Greece	Italy
S	0.033506	0.101844
a	−13.37139249	−12.7713
b	1.38922807	1.557124
	$b_{21} = 0.02556$	$b_{12} = 0.0002$

Table 12 Adjusted diffusion estimation after cross-national methodology application

Year	Greece $F_1(t)$	Italy $F_2(t)$
1996	6.69975E–05	0.0006
1997	0.0002	0.0032
1998	0.0011	0.0135
1999	0.0039	0.0429
2000	0.0110	0.0790
2001	0.0214	0.0960
2002	0.0289	0.1005
2003	0.0318	0.1015
2004	0.0326	0.1017
2005	0.0328	0.1018
2006	0.0328	0.1018
2007	0.0328	0.1018

6 Analysis of results and methodology extensions

The present work intents to capture and estimate the portion of diffusion effects that corresponds to adjustments of the initial estimations due to the influential factor between countries, or otherwise defined areas. Apart from cross area influence, a number of other, possibly more influential factors, are also responsible for the diffusion pattern of a newly introduced product. Product's introduction price and advertising efforts are included among them. The cases that were evaluated in this work were selected so as to reflect a somewhat expected result and towards this direction, the proposed methodology attempted to quantify this result. More specifically, there are a number of underlying social and economic reasons that can be taken under consideration in order to support that Western Europe's maturity in technological adoption will play an influential role over Eastern European countries. It is also evident that Eastern European countries are making their moves towards increasing telecommunications development, especially after many of them have become member states of the European Union. Similar suppositions can be made for the case of Latin and North America. North America is a leader in technological innovations and corresponding adoption rates of high technology products. On the contrary, Latin America has fallen behind in technological market maturity, due to a number of social and economic reasons which strengthens the expectation for North America to cause adjustments in Latin America's adoption rate and not vice versa. Finally, for the case of Greece and Italy, empirical evidence from similar services such as the internet and computer usage revealed that Italy is more mature than Greece. Thus, the latter country constitutes a follower in adoption of high technology products, while Italy can be considered as a leader.

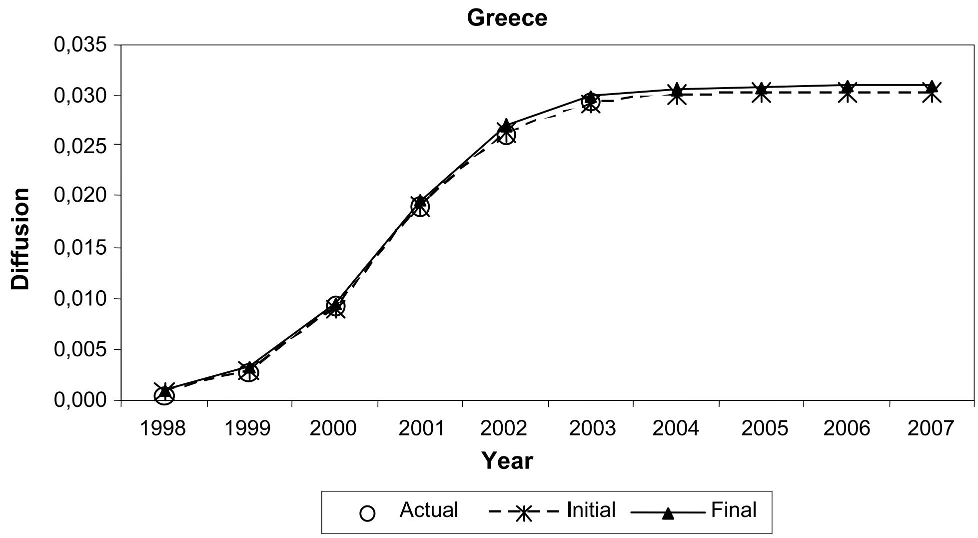

Fig. 6 Cross-national diffusion results, Greece

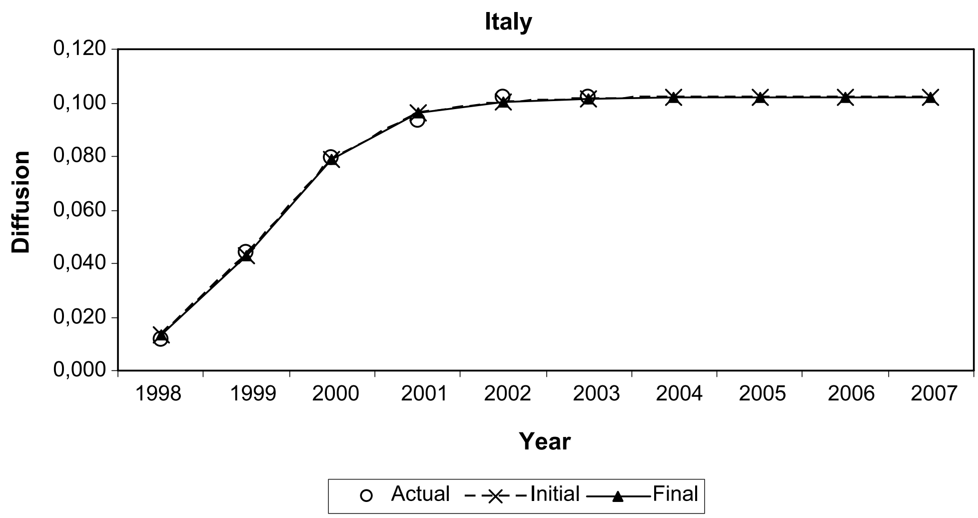

Fig. 7 Cross-national diffusion results, Italy

The term leader that was used for North and Latin America as well as for Greece and Italy, does not have the meaning of the time lag, but it is used to describe the maturity of the corresponding market. Thus, Italy is considered a leader country in the sense that the Italian population is more willing to adopt a newly introduced technology, which in turn speeds up diffusion process.

As stated at the beginning of the section, the presented work introduces and accesses the impact of the influential factor over diffusion process, which is achieved by incorporating this factor into the initial formulation of a diffusion model. However, as also stated, cross national, or cross area in general, influence is not the most crucial factor in a product's life cycle, as pricing and advertising play a more important role for a successful diffusion process. Towards this direction, the presented methodology can be further developed by incorporating the pricing or the advertising efforts, or both in a more complex formulation, so as to describe and quantify the elasticities of these parameters. More specifically, the introductory stage of a product's diffusion process is usually followed by a high initial pricing policy and a wide advertising which corresponds to substantial business expenses and costs. Following that stage, price usually declines as well as advertising expenses. Depending on the product's elasticity over each of the other two parameters, diffusion is affected, positively or negatively. This may trigger a reaction regarding pricing or advertising, in the sense that if the sales' level is not as high as expected companies may invest more on advertising. On the other hand, a successful sales' level may lead to a cheaper product for the users, which may in turn boost sales. Some work related to these aspects is presented in [18], where the interaction between diffusion and pricing is examined while diffusion and pricing schemas are estimated and forecasted.

Another extension of the proposed approach refers to the concept of generation substitution, which is the usually case in high technology markets. During a product's life cycle, a new generation of the product or another substitute product is introduced, which causes adjustments to the initially estimated diffusion process. This happens because the new product, or the new generation of the existing, one attracts adopters who would otherwise adopt the existing generation. Consequently, the formulation of diffusion estimation should incorporate the portion of the market that is not expected to adopt the innovation, in order to caption the generation or product substitution impacts.

7 Conclusions

This work intends to capture the cross-national diffusion effects, whenever a new product is introduced in a number of markets with different characteristics. The definition of cross-national, is not limited to country segmentation, but can be extended to include all kinds of market segmentation, like different areas in the same country, or continents in the whole. Given that definition, a study of interest would be the validation of the methodology, over the diffusion process of a telecommunications product, within the boundaries of the same country. This could give an estimation of the influence of the capital city of the country, or other major cities, over the decentralized areas, and the impact on the initially estimated diffusion parameters, and adoption rates.

Moreover, as similar methodologies were evaluated over consumer durables only without considering the possible peculiarities of the telecommunications area, this work focused mainly on evaluating the interaction of telecommunication markets. At this point, it should be clarified that the application of such a methodology is not expected to reveal major changes, but calculate adjustments to the initially estimated diffusion parameters.

The methodology presented can be extended to capture the "lead-lag" effect, which is the case when a product is introduced in a number of markets with a time delay. The effects of the lead country over the lag one are expected to noticeably influence the adoption rate of the product within the lag country, as previous research has revealed that the later the product is introduced in the lag market, the greater the influence over the diffusion process would be.

Future work could also include the expansion of the methodology so as to capture the cross-area impact in more than two areas, focusing on the telecommunications sector products. Even more, as presented in the preceding section, development of such kind of diffusion models can be directed to accommodate the impact of other exogenous factors apart from cross-national influence, such as pricing, advertising and generation substitution impacts.

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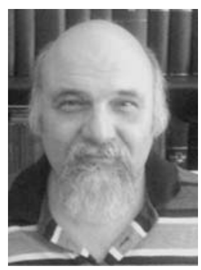

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