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On the construction of price index and the definition of factors affecting tariffs of ADSL connections across Europe

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Abstract Following a discussion about the factors affecting the evolution and adoption of telecommunications and especially broadband communications, namely subscribers' profile, market competition as well as users' income and willingness to pay, in this work an overview of tariffs for Asymmetric Digital Subscriber Line (ADSL) connections across Europe is presented and a hedonic model is applied in order to identify and estimate the characteristics which are of substantial influence of the broadband prices' shape. Finally, a price index for ADSL connections is constructed.

Keywords ADSL connections · Broadband communications · Hedonic model · Technological innovation · Competition · Price index

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1 Introduction

During the last decade, home and Small Office/Home Office (SOHO) broadband access received a lot of attention across Europe. Among wireline broadband alternatives, telecom operators focused on providing Asymmetric Digital Subscriber Line (ADSL) access, since they exploit the existing copper lines and upgrade the network infrastructure at a relatively low cost. Since broadband connections are "always on", a variety of broadband services such as high speed Internet access, voice over IP and high definition television (HDTV) encourage customers to stay on line for longer, which in turn leads to the development of e-commerce that "*...enable companies to lower costs such as...selling and distribution*, *which will lead to the development of new markets and services*." [8].

On the other hand, the trade-off between an appropriate service basket and an affordable, by the customers, price, becomes a critical issue for the evolution of broadband penetration. It is obvious that the battle for a dominating market share grows the competition among telecom operators and leads to the development of new technologies in order to meet the market demand. In the near future, operators will also be able to provide the same type of service, with the same quality in every place of a country [5] and this technological development will give equal rights to information access for all customers. In order to keep the broadband market evolution at affordable price levels, several initiatives and business cases have been developed, comprising improved technological infrastructure, tariff subsidization and new service baskets.

The present work attempts to explain the aforementioned observations and to answer to some of the questions raised. Towards this direction, the rest of the paper is organized as follows. In Section 2, the factors that provisionally affect broadband expansion are analyzed and situation across Europe is briefly presented. In Section 3, the hedonic approach is presented, discussed and applied over European ADSL market. Numerical results are presented and discussed. Finally, Section 4 concludes the analysis.

2 Background

Among the most important factors that affect the expansion of broadband services, the investments in the telecom sector, the technological enhancements of existing network infrastructures, the gross domestic product (GDP), as well as the competition among operators are some of the most critical ones. In addition, the subscribers' profile, the governmental policies and initiatives towards the development of the telecom market are also of substantial importance.

2.1 Investments and GDP

In general, the required equipment and network infrastructure are significant parameters to be incorporated in an effective and thus successful business

case. It should however be taken into account that the equipment cost is decreasing over time due to mass production [1], while other significant costs include maintenance and repairing costs of the existing network infrastructure, licenses costs for software, hardware and rights of use, marketing costs for promoting a product and installation costs for customer premises equipment. Although a number of approaches have been proposed in order to estimate the above parameters, the running costs remain the most difficult to estimate parameter, due to their relation with market competition and technology risk which mandates the introduction of new services in replacement of old ones.

In addition, it has been recorded that higher-income households are using Internet more often, for a longer period of time [4] and for different services (e.g. online shops, e-banking services, online video and audio services etc.) while inhabitants of urban areas are more likely to use Internet than others who live in suburban or rural areas. Thus, any investment strategy in the latter areas, will be dominated by higher investment risks and a long period of payback [7], which in turn leads in growing inequalities of the broadband access among different geographical regions.

2.2 Technological innovations

Telecom operators, following the growing political interest (e.g. e-Europe 2005 initiative), are expected to provide broadband communication services in all geographical regions, necessitating the infrastructure upgrades as inevitable. As a result, network operators are enforced to increase the available bandwidth, in order to provide more services to their customers. This is achieved mainly by replacing parts of the existing networks with fiber infrastructure, especially in areas with specific characteristics, such as high density of potential subscribers. In addition, they have to identify these characteristics and make accurate business plans, in order to ensure a secure profit after upgrading their network. More specifically, they should examine a series of characteristics in urban, suburban and rural areas, such as the necessary cable length for the expected connections, the number of subscribers per square km, the number of buildings in each specific area, as well as the number of potential subscribers per building [7]. As a consequence, detailed study and dimensioning of the necessary network infrastructure for the provision of broadband services under specific traffic characteristics should be extracted. At this point, it is worth mentioning that in North Europe, the differences between rural and urban areas concerning the use of Internet are quite small, while the differences in South Europe are quite observable [8]. Rural areas of Northern Europe have a population density leading to very high costs of network infrastructures, but on the same time, demand for broadband services is also high. Therefore, acceptable business cases can be foreseen. On the contrary, in South Europe the situation is quite different. In rural areas, even with high population density, the demand for broadband services remains low, as a result of social and economic differences with urban areas.

2.3 Subscribers' profile

As more people across Europe are accessing Internet, its penetration presents differences across European countries due to a series of characteristics such as age, level of education, income and family type [4]. Children and teenagers are interested in Internet mainly for playing games, communicating, listening to the music or for educational services, while adults usually prefer e-mail access, health and tourism information, electronic banking and e-shopping services. In addition, the educational level remains an important factor, since higher-educated subscribers are more familiar with new technologies [10] and are more willing to use Internet for their needs.

There is also a strong dependence between income and Internet usage, since households with high incomes have a stronger effect on technology adoption, as they have already used some kind of access technology in the past, obtaining the necessary familiarity. Therefore, it can be expected that, in developing countries, potential customers with higher income can afford higher prices for improved services [11].

Another characteristic of the broadband subscribers' profile is its family type. The use of Internet seems to be higher in families with children, instead of families with no children, or one-person households, since more persons are willing to share the same access for different reasons and preferences.

2.4 Competition among operators

Telecom operators, in order to ensure high Quality of Service (QoS) and reliability of Internet access offer a number of alternatives, according to the customer demands and affordability. As a result, a fierce competition among them is taking place so as to attract more subscribers [3]. For example, some of them offer free extra time of Internet connection, the duration of which depends on the bandwidth offered. There is also a great difference between the residential and business packages offered. There are low price Internet connections that are designed to attract residential customers, while the most expensive ones, providing higher speed connections are designed for business customers. Free dial-up Internet access is also provided in some countries, under the assumption that telephone companies share revenues with free Internet access providers [2].

2.5 Governments' policies and initiatives

Governments also promote broadband communications, since the information flow through Internet includes health, tourism, entertainment and commerce oriented services [8]. In general, the promotion of broadband services has a positive effect to economic activity and speeds up the economic development [9] while such policies will improve the quality of life and modernize the less developed areas. Consequently, as the governments recognize the need for special attention, treatment and confront in rural areas, they are taking active

Table 1 Required bandwidth for typical broadband services

Service	Bandwidth (Mbps)
HDTV	16–20
Telemedicine	6
VoD	6–18
Internet access	1.5
Video conferencing	1.5
Telecommuting	3
Multiple digital TV	6–24

HDTV High definition TV, *VoD* video on demand

measures by creating network infrastructures or supporting relative initiatives of the private sector, which lead to high speed Internet access, so that all citizens can participate in an information society.

2.6 Typical ADSL service baskets

The competition for the "last-mile" broadband deployment enables providers to enhance system performance, by adopting current and evolving access technologies, thus providing a wider range of services and applications. Among the several characteristics, the offered data rate is the most important for the classification of broadband services and applications. During the last years, the domination of ADSL technology demonstrated the deployment of services with data rates up to several tens of megabits per second (e.g. high-speed Internet access and IP-telephone). However, evolving and future fixed and wireless access technologies promise tenfold data rates [6], thus enabling the provision of bandwidth-consumed services (e.g. HDTV and video on demand), according to Table 1.

The specification of a basic basket of broadband services is essential for its technoeconomic evaluation. For this purpose an extended survey, regarding the ADSL residential connections, across 15 European countries was conducted [18], aiming to the exploration of the offered services and the tariff policy. Eventually, the typical ADSL service basket, (Fig. 1) was determined as a combination of main and additional services. The main services include

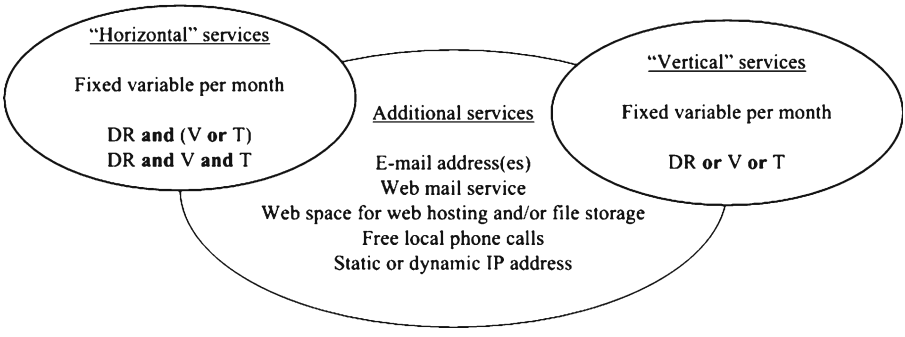

Fig. 1 Typical ADSL service basket

two options. These are either a concurrent or an individual offer of a supported data rate, a maximum consumed data volume and a maximum allowed time online. The additional services include a number of email addresses, a sufficient web space for web hosting and/or file storage and optional free local phone calls and static IP address.

3 The theoretical hedonic model and its application to ADSL prices

3.1 Introduction

Hedonic methods are based on the idea that a service (product) is a bundle of characteristics and that consumers just buy bundles of product characteristics instead of the product itself. The observed price of a product (service) is considered to be a function of these characteristics. These methods can be used to construct a quality-adjusted price index of a service. An overview of hedonic price equations is presented in [14] and [15]. Moreover, in [16] the fact that from a large amount of product varieties, consumer chooses without influencing prices is presented. All of them are based on some estimated coefficients that are inflicted on the characteristics of the products in both consecutive time periods: m and $m + 1$. Someone can estimate the coefficients separately for every year, or can have observations of two or all years together and estimate a common set of coefficients. The advantage of this method is that the included calculations are easy and fast to implement. Hedonic methods are indeed very fast to apply but the disadvantage is that index price can change even if no new products are existed, or all prices remain the same.

The hedonic price indices are commonly used as approximations to the true cost-of-living indices which indicate how much money a consumer would need in period $m + 1$ relatively to the amount of money he needed in period m, so as to keep the same level of utility [17]. The solution is to determine the consumer's profile and his reaction to a varied and fast-changing supply of products. But how can this profile be determined when everyone has different needs and requirements? However and according to this approach, the price index is constructed only by using the prices of products, which are available in two adjacent periods.

3.2 The hedonic method

A hedonic function is a relation between the prices of different varieties of a product, such as the various ADSL connections offered, and their characteristics. In general, a hedonic model is described by the following equation:

$$P_i = f(X_i) \tag{1}$$

where P_i is the price of a variety (or a model) i of a product and X_i is a vector of variables.

In the economic science literature, the variables of a hedonic function are called characteristics or determinants. The hedonic function is then used, for different characteristics among the varieties of the product considered, in order to calculate the price index. Many functional forms have been used in hedonic research, including research on various products such as computers, house bargain, wines' preference etc.

After determining which characteristics have to be considered, the following equation [12] is estimated for N telecommunication products in period m and in period $m + 1$:

$$P_{im} = b_0 + b_1 f(X_{1i}) + b_2 g(X_{2i}) + u_{im}, i = 1, ..., N \quad (2)$$

$$P_{im+1} = b_0 + b_1 f(X_{1i}) + b_2 g(X_{2i}) + b_3 + u_{im+1}, i = 1, ..., N \quad (3)$$

where b_i are some constant coefficients that have to be estimated and X_1, X_2 are unique characteristics of the $i-$th product (the independent variables of the econometric model). X_1 and X_2 variables participate into the hedonic model through the functions f and g. The meaning of this equation is that the price P (dependent variable) of any product i, at time m, depends on its characteristics X_1, X_2. Finally, b_3 can be other variables–characteristics of the product, which did not exist at time m but may have appeared in time $m + 1$. The u_{im} is a regression residual, which acts as an indicator of the price of the particular product i, being close to the regression line at time m.

3.3 The ADSL hedonic model

Following the theoretical presentation of the previous sections, a hedonic model was applied, in order to study a typical ADSL basket across the European countries. The evaluation was based on data for ADSL connections, which were collected from year 2003 to 2005 for both residential and business connections. Of course there is a large variation of values of the participating variables, as well as in price levels between the participating countries, for the same service considered. As observed in Table 2, from year 2003 to year 2004

Table 2 Prices and capacities from 2003 to 2005

Year	Min	Mean	Max
Subscription price (€)			
2003	12.95	80.45	339
2004	6.73	44.81	170
2005	3.99	46.79	181
Downstream bandwidth (kbps)			
2003	250	872.22	3,000
2004	250	2,152.77	24,000
2005	256	4,284.93	26,000
Upstream bandwidth (kbps)			
2003	128	186.67	432
2004	128	660.89	24,000
2005	128	878.01	26,000

there was a significant reduction in subscription prices on the one hand and an evolution on capacities' values which is about 30% on the other.

Evaluation data were collected from 15 European countries, namely Austria, Belgium, Denmark, Finland, France, Germany, Iceland, Italy, Netherlands, Norway, Spain, Sweden, Switzerland, UK, and Greece. In addition, the prices correspond to all operators, no matter the number of subscribers they have.

By applying a multiple regression hedonic model to the ADSL connections data, the best fitting function for every year (2003, 2004 and 2005), turned out to be:

$$P_{im} = b_0 + b_1 D\left(\text{Mbps}\right)_i + b_2 U\left(\text{Mbps}\right)_i + b_3 \ln V\left(\text{Gbps}\right)_i + b_4 \ln\left(\text{GDP}\,(€)^2\right)_i + b_5 \ln\left((\text{OP})^2\right)_i + b_6\,\text{DUR}_i \quad (4)$$

where D and U is the downstream and upstream data rate in Mbps, respectively,

V is the maximum free data volume in Gbps,
GDP is the gross domestic product of each country in €,
OP is the number of operators in each country and
DUR is the downstream to upstream ratio and
m is the observation year.

Finally, coefficients $b_0$to b_6 are constants and they are the corresponding weighting factors. Table 3 shows the results of fitting by a multiple linear regression model, in order to describe the relationship between the subscription price and the six aforementioned identified variables. The standard error of the estimation shows the standard deviation of the residuals, where the mean absolute error is their average value. The P-value that appears in the results' table is related to the probability for the corresponding parameter to be equal to zero (null hypothesis). So, this parameter can be considered as less significant for the model, the evolution of broadband tariffs in the presented case. Finally, since the coefficient determination (R^2) is in excess of 94% the validity of the above model is even more strengthened.

Table 3 Regression analysis

Parameter	Estimated coefficients	Standard error	P-value
Downstream (Mbps)	−26.01	8.38	0.0210
Upstream (Mbps)	300.30	58.54	0.0022
Ln (operators^2)	9.26	3.68	0.0456
Ln (GDP^2) (€)	−15.16	11.23	0.2258
Downstream to upstream ratio	6.178	2.34	0.0388
Ln (volume) (Gbps)	15.28	4.46	0.0141

R^2 = 94.84%
Standard error of estimation = 7.55
Mean absolute error = 3.49

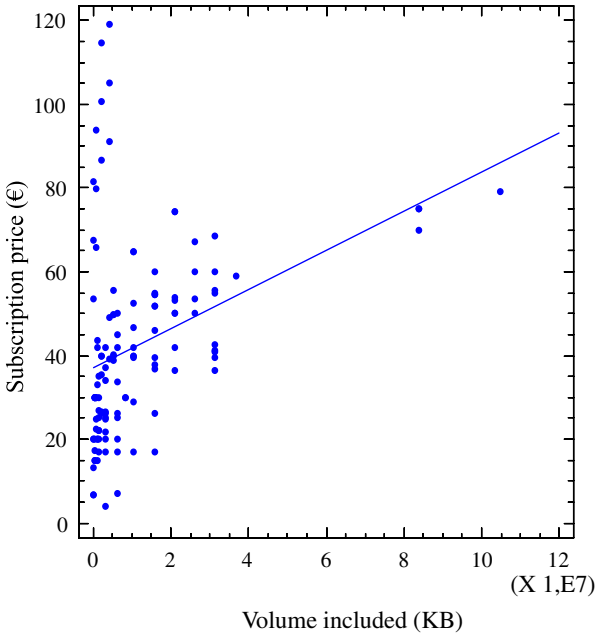

Fig. 2 Volume vs. subscription price

It is noticeable that the highest P-value [13] of the independent variables is 0.2258 and belongs to $\ln(GDP^2)$. This finding is quite critical as far as the null hypothesis of the GDP impact to ADSL prices is concerned and it should be further analyzed in order to justify the arguments about the influence of user' income to broadband prices.

As far as the other parameters are concerned, the analysis undertaken justifies the impact of bitrates (both downlink and uplink) to the price of ADSL subscriptions. The parameters as well as the downstream-to-upstream ratio (the asymmetry ratio) are the easiest characteristics to be identified by the user and thus the most influential ones.

Figures 2 and 3 present the shape of the subscription prices in connection with the maximum allowed volume data and maximum allowed time respectively, which are offered in every package. It can be observed that there is a growing trend in subscription price as both allowed volume data and time are also increased.

Figure 4 shows the shape of the subscription prices in connection with the downstream to upstream ratio. It is clear that there is a remarkable trend for keeping the subscription price constant, as the downstream to upstream ratio increases on the same time.

3.4 Constructing the price index

Using data such as those presented in Table 4, for the case of Europe, it can be observed that it is not easy to compare prices for different characteristics such as data rate, consumed volume, allowed time on line, but there are similarities

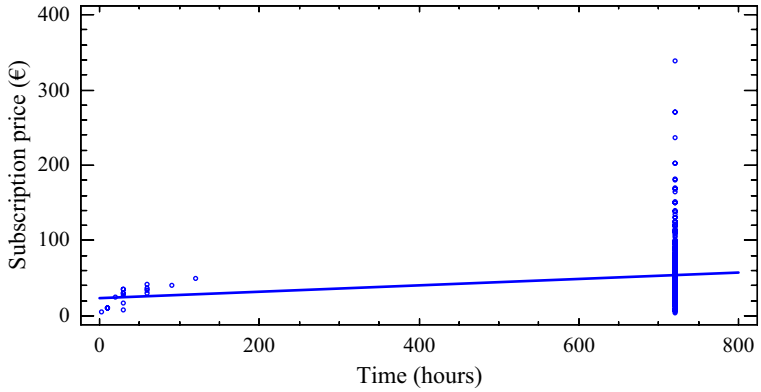

Fig. 3 Time vs. subscription price

and patterns that must be evaluated. Based on calculation of the minimum, the mean and the maximum for all data as presented in Table 2, it can be observed that there is a remarkable upward trend in downstream and upstream. On the same time, the subscription price for year 2004 is 50% less than this of 2003, but for the period 2004–2005 it is approximately the same. However, in countries such as Belgium and the Netherlands, prices were reduced during 2003–2004 but in 2004–2005 remained almost the same, whereas in other such as Spain there is a continuous reduction across years. Therefore, the average value of prices of ADSL connections and their characteristics (downstream and upstream) was computed for all countries (Fig. 5), in order to provide an estimation for prices and physical characteristics (downstream and upstream) of a typical European ADSL connection. Once more, it can be observed that downstream and upstream data rates seem to follow a linear path over years

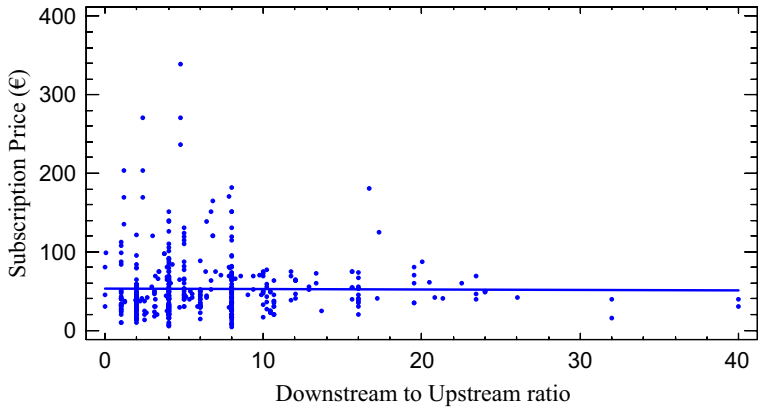

Fig. 4 Downstream to upstream ratio vs. subscription price

Table 4 Data for ADSL connections

Subscription price (€)	Data rate (down) (Kbps)	Data rate (up) (Kbps)	Volume (Mbps)
59.95	10,000	512	15,360
14.95	256	64	307.2
21.95	1,536	256	1,536
29.95	800	256	–
74.95	12,000	1,024	8,192

(solid line in Fig. 5), thus reflecting the findings presented in Table 2. In addition there is an evolution in data rate and especially in the down stream.

Finally, since there are N telecommunication products in the period between m and $m + 1$, by considering Eq. 4 which describes the relationship between prices and characteristics, in a variety of ADSL products, the proposed hedonic price index can be expressed by the following equation:

$$I_{m+1/m} = \hat{f}_{m+1}\left(\hat{b}_k X_i\right) - \hat{f}_m\left(\hat{b}_k X_i\right) \quad i = 1, \ldots \ldots, n, \; k = 1, \ldots, 6 \qquad (5)$$

This behavior fits to the hedonic approach and it can be observed by calculating the hedonic price index from Eq. 5. In Fig. 6, the calculated index and its evolution are presented for the case of European countries broadband market. It is observed that for the period 2003–2004 there is a trend of 50% reduction in prices. However, this does not apply for the period 2004–2005, when the price index is approximately close to 1, which means that prices for ADSL services remain the same.

Taking into account that there is a significant trend in upgrading downstream and upstream bandwidth, it can be extracted that there is an implicit reduction of prices in terms of Mbps/€, since operators offer better services and bitrates but the final price remains more or less the same and it is strongly affected by other parameters as well. As far as the period 2003–2004, the

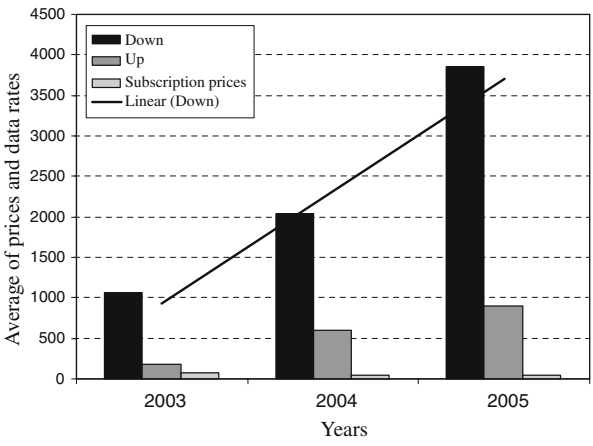

Fig. 5 Evolution data rate (down) in Europe

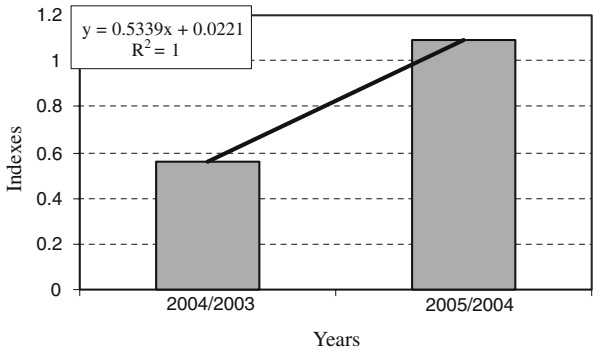

Fig. 6 Hedonic price index evolution for the case of ADSL market in Europe

reduction of price index should be also compared with changes in market shares or market structure in general, which has not be analysed in this work.

4 Conclusions

In this paper, a study of the dominant characteristics that affect the tariff policy of ADSL services is presented. It is shown that the general trend is the decrease of subscription prices, as probably expected, but the competition between operators leads to more and more attractive ADSL services baskets, which in turns leads to increase of downlink and uplink data rates, since these parameters designate the perceived by the users QoS. As a result, in many cases the prices remain the same while the data rates are increasing.

This analysis aims to identify these trends of prices for telecommunication services (products) and especially ADSL connections over time across all European countries, by applying a hedonic method for some defined characteristics. This method performs well when the set of important characteristics remain the same, but less satisfactorily when these characteristics change rapidly over time and thus some of them might disappear for ever or be substituted by another characteristic [12]. However, in this study the most significant characteristics of ADSL services were considered, since they are the most critical ones that designate the quality of ADSL access as described in Section 3 and they affect the price of ADSL continuously. Furthermore, additional parameters that might influence ADSL's prices have been included in the model, in order to perform a more precise estimation of hedonic indexes.

In conclusion, the results give an overview of telecommunication prices over time and show how the prices will be fluctuated during the next years. The application of these econometric methods, following the definition of products' characteristics, provides a reliable and accurate method able to produce an exact estimate of prices for new products over the next years. The validity of the model and the appropriate selection of the functional form that has been chosen to relate price to characteristics can be validated over next years and more observations. However, as the factors affecting broadband tariffs can be

numerous, a more detailed study that takes into account additional parameters is always needed.

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References

1. Varoutas, D., Kamalakis, T., Katsianis, D., Sphicopoulos, T., & Monath, T. (2007). Techno-economic evaluation of optical access and metropolitan area networks: The influence of the status of maturity of the photonics component industry. In *Proc. IEEE/OSA OFC 2007*, Anaheim, CA, USA, 25–29 Mar 2007.
2. Haan, M. (2001). The economics of free internet access. *Journal of Institutional and Theoretical Economics, 157*(3), 359–379. doi:10.1628/0932456013621260.
3. Goff, D. H. (2002). An Assessment of the Broadband Media Strategies of Western European Telecoms. In *Proc. 5th World Media Economics Conference*, Turku, Finland, May.
4. Dickenson, P., & Ellison, J. (1999). *Plugging in: The increase of household internet use continuous into 1999*. Ottawa: Connectedness Series, Statistics Canada.
5. Valiente, J. (2002). *The principle of non-discrimination in the ADSL market*. Brussels: European Internet Services Providers Association (EuroISPA).
6. ECOSYS (2004). *Deliverable 2, overview of demand forecasts for the fixed and mobile networks and services in Europe*. ECOSYS, October.
7. Monath, T., Elnegaard, K., Cadro, P., Katsianis, D., & Varoutas, D. (2003). Economics of fixed broadband access network strategies. *IEEE Communications Magazine, 41*, 132–139. doi:10.1109/MCOM.2003.1232248.
8. Kalhagen, K. O., & Olsen, B. T.(2002). Provision of broadband services in non-competitive areas in Western Europe countries. In *Proc. ISSLS*, Seoul, Korea, April.
9. Kim, C., & Galliers, R. D. (2004). Toward a diffusion model for Internet systems. *Internet Research Journal, 14*(2), 155–166. doi:10.1108/10662240410530862.
10. Lu, J., Yu, C.-S., Liu, C., & Yao, J. E. (2003). Technology acceptance for wireless internet. *Internet Research Journal, 13*(3), 206–222. doi:10.1108/10662240310478222.
11. Madden, G., & Coble-Neal, G. (2005). Australian residential telecommunications consumption and substitution patterns. *Review of Industrial Organization, 26*, 325–347. doi:10.1007/s11151-004-6617-z.
12. Triplett, J. (2004). *Handbook on hedonic indexes and quality adjustments in price indexes: Special application to information technology products*. OECD Science, Technology and Industry Working Papers.
13. Goodman, S. (1999). *Toward evidence-based medical statistics. 1: The P value fallacy*. Annals of Internal Medicine, 130(12), 995–1004.
14. Berndt, E. R. (1991). *The practice of econometrics: Classic and contemporary*. London: Addison-Wesley.
15. Triplett, J. E. (2000). *Draft copy handbook on quality adjustment of price indexes for information and communication technology products*. Paris: OECD.
16. Rosen, S. (1974). Hedonic prices and implicit markets: Product differentiation in pure competition. *The Journal of Political Economy, 92*, 34–55. doi:10.1086/260169.
17. Jonker, N. (2001). *Constructing quality adjusted price indexes: A comparison of hedonic and discrete choice methods*. De Nederlandsche bank, Econometric Research and Special Studies Department.
18. ECOSYS (2005). *Deliverable 14, updated forecasts for the mobile and fixed broadband networks and services*. ECOSYS, December.