

Petre, Konstantin; Chipouras, Aristides; Katsianis, Dimitris; Varoutas, Dimitris

Conference Paper

Anticipating High-Speed Broadband Penetration: A Multi-Country Pre-Launch Forecasting Study

32nd European Conference of the International Telecommunications Society (ITS):
"Realising the digital decade in the European Union – Easier said than done?", Madrid,
Spain, 19th - 20th June 2023

Provided in Cooperation with:

International Telecommunications Society (ITS)

Suggested Citation: Petre, Konstantin; Chipouras, Aristides; Katsianis, Dimitris; Varoutas, Dimitris (2023) : Anticipating High-Speed Broadband Penetration: A Multi-Country Pre-Launch Forecasting Study, 32nd European Conference of the International Telecommunications Society (ITS): "Realising the digital decade in the European Union – Easier said than done?", Madrid, Spain, 19th - 20th June 2023, International Telecommunications Society (ITS), Calgary

This Version is available at:

<https://hdl.handle.net/10419/278013>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.

Anticipating High-Speed Broadband Penetration: A Multi-Country Pre-Launch Forecasting Study

Konstantin Petre¹, Aristides Chipouras¹, Dimitris Katsianis², Dimitris Varoutas¹,

¹Department of Informatics & Telecommunications, National and Kapodistrian University of Athens, Athens, Greece (kpetre.arischip.d.varoutas@di.uoa.gr)

²Department of Digital Industry Technologies, National and Kapodistrian University of Athens, Athens, Greece (dkats@uoa.gr)

Abstract

The objective of this study is to develop a new approach for pre-launch forecasting of the high-speed broadband diffusion among European community countries. However, producing such forecasts is a complex and challenging task mainly provided that past time series data concerning the relative telecom services are unavailable. Besides, multiple factors can affect adoptions such as customer heterogeneity as well as macro-economic and technological conditions. So, a multi-country method that incorporates well known diffusion models is proposed. By econometric assistance, our approach aims to capture more reliable projections in cases where the penetration is extremely immature due to lack of data. Concerning the broadband penetration in terms of download speed, rates as 100 Mbps or more seems to be mature in most countries. However, even for countries as Sweden and Romania, where penetration reached too high in downlink category (1000 Mbps or more), safe and accurate predictions cannot be deployed, as the diffusion of innovation theory argues that the level of penetration must be at least above the turning point. This area of research is important for telecom operators, as the overestimating of the demand can lead to excess inventory, while an underestimation can incur significant opportunity costs and reduced market share.

Keywords

Multi-country diffusion, Multi-generation diffusion, Pre-launch forecasting, Bass model, Multivariate linear regression

1. Introduction

High-speed broadband is vital for stimulating economic progress, social inclusion and innovation in the digital era. However, predicting how high-speed broadband will be adopted by different countries and speed categories is a highly uncertain and complex task, even more, when historical data is insufficient or unreliable. In this paper, we propose a new approach for forecasting high-speed broadband diffusion in the European Union before it is launched, based on a multi-country method that applies well-known diffusion models and econometric techniques. We use bi-annual data on fixed broadband penetration in each speed category from December 2007 to December 2021 to estimate the parameters of four diffusion models: Logistic, Gompertz, Bass and Log-Logistic. We then apply regression analysis to project the parameters of the next speed category (≥ 1000 Mbps) for each country, using variables such as download speed, GDP per capita and DSL share. We demonstrate our approach with illustrative examples for three countries: Romania and Sweden, where the adoption of Gigabit connections has reached significant levels compared to other European Union countries, and Germany, where the adoption of Gigabit

connections is still in its early stages. We also examine the migration from previous speed categories and track their evolution until their eventual obsolescence. Our approach aims to provide more reliable and flexible projections for high-speed broadband diffusion in cases where the penetration is extremely immature. The rest of the paper is organized as follows. In section 2, we review the relevant literature on diffusion models and forecasting methods for high-speed broadband. In section 3, we describe the data sources and the diffusion models that we use for our analysis. In section 4, we present the methodology for projecting the parameters of the next speed category and forecasting the diffusion curves. In section 5, we report and discuss the results of our projections for three countries: Romania, Sweden and Germany. In section 6, we conclude and offer some implications and directions for future research.

2. Literature review

Several approaches to producing pre-launch forecasts have been proposed in previous studies when little or no data are available. Thomas [1] examined a model involving a new type of electronic mail service, based on the identification of similar products and the assumption that consumer utilities for the attributes of the new product are a function of the utilities for the attributes of analogies, the estimates of the p' and q' Bass parameters are formulated weighted by attributes. Unfortunately, because the data were based on frequency counts of the strengths and weaknesses (number of mentions), there were no measurement scales to clearly establish specific values or relative importance's of the attributes among consumers at the individual level. Consequently, the proportion of mentions (strengths and weaknesses) were computed as surrogate measures of the relative importance of the various attributes.

Similarly, Srivastava *et al* [2] developed a diffusion model that incorporates potential adopters' perceptions of the relevant innovation attributes in explaining the rate of adoption of an innovation. Data from 14 investment alternatives available to consumers were used to develop a multi-attribute diffusion model of five attributes for forecasting the acceptance of a potential investment alternative. Due to the high correlation between these attributes, however, only two attributes, information costs and likelihood of loss of principal, are employed to forecast the acceptance of a potential investment alternative.

Gatignon *et al* [3] develop a cross-national econometric model of innovation diffusion. Their methodology can provide estimates for the diffusion parameters in countries that have not adopted the innovation yet, or for countries where data are not readily available, which is a common situation in international marketing research. In their study it was postulated that the fluctuations of the Bass diffusion parameters across countries can be partially "explained" by the social system characteristics as represented by the cosmopolitanism, mobility, and sex role variables. First market potential is estimated for each product and each country separately, using Ordinary Least Squares (OLS), but in cases of insufficient data as discussed by Heeler and Hustad [4], management can provide a priori sensible limits on the saturation parameter.

Lee *et al* [5] examined the pre-launch forecasting of new product demand based on the Bass model and statistical and machine learning algorithms. The Bass model is used to explain the diffusion process of products while statistical and machine learning algorithms are employed to predict two Bass model parameters. In their approach six statistical and machine learning-based regression algorithms were utilized to identify the relationship between diffusion parameters and product attributes. Ensemble prediction models were constructed in order to enhance the predictive power where the prediction performance compared to the analogical method and statistical and machine learning algorithms.

In a recent study of Yin *et al* [6], they developed a hybrid demand forecasting model combining clustering analysis and deep learning. Based on the product similarity measurement, the weight of product similarity attributes is realized by using the method of fuzzy clustering-rough set. By determining the significance of similar products and collecting the sales data of these products, the method provides data support for the initial forecasting of new products. To overcome the limitation of Bass model, they use LSTM neural network to embed the influences of product heterogeneity, season, and product sales period on the demand, and they adjust the prediction error to improve the prediction accuracy.

3. Dataset and Models

Using bi-annual data on fixed broadband penetration in each speed category from December 2007 to December 2021, we investigate in every country of the European union which is the optimal model to predict the penetration of each data speed category. The data in this study come from European commission for each member country and describe the share of fixed broadband subscriptions that are greater than 10 Mbps, 30 Mbps and 100 Mbps[7]. The models that will be compared are Logistic, Gompertz, Bass and Log-Logistic. The premise is that each speed class tends to supersede its predecessors, gaining the potential for 100% saturation level. As a result, the degrees of freedom for each model are reduced to 2 from 3, since there are only two parameters left to be estimated via regression. This approach gives more flexibility to the parameter estimation process, while the saturation levels remain constant. After this stage of the process, each result will be converted to a Logistic basis, as the parameters have a different interpretation. For example, in the Logistic model, the time shift parameter describes the moment when the penetration reaches the level of 50%, while in the Gompertz model it is associated with 36.79% adoption.

The diffusion models that have been introduced, by Petre and Varoutas[8], will serve as the foundation for our analysis. However, certain adjustments will be made in the current approach. In particular, the time shift parameter will be modified to represent the desired time period, expressed as $(t-b)$, and the diffusion speed will be placed in the denominator of the model equation to be captured with values greater than one, rather than using the notion of zero point, for aesthetic considerations.

The Diffusion models used for estimating the adoption of High-Speed Broadband Penetration in EU are as follows:

$$\text{a) Logistic model: } N(t) = \frac{S}{1+\exp((t-b)/a)} \quad (1)$$

$$\text{b) Bass model: } N(t) = S * \frac{1-\exp(-(q+p)*t)}{1+\frac{q}{p}\exp(-(q+p)*t)} \quad (2)$$

$$\text{c) Log-Logistic model: } N(t) = \frac{S}{1+\exp(-(\ln(t)-b)/a)} \quad (3)$$

$$\text{d) Gompertz model: } N(t) = S * \exp(-\exp(-(t-b)/a)) \quad (4)$$

where, $N(t)$ represents the total penetration at time t , S the saturation level of the Broadband Penetration and the diffusion speed will be represented by the parameter a . The b is the parameter that will indicate the time it takes to achieve 50% adoption, while the coefficients p and q will respectively signify the innovation and imitation factors.

4. Methodology

Download speed is a representative indicator for the broadband of telecommunication services. Choosing download speed categories was a complex decision-making process. This is because there is no single categorization despite the existence of the European Union's Digital Agenda until 2030. In the table 1 the prevalent categories defined by the Digital Agenda of EU are presented as well as the relative ones adopted by the National Regulatory Authorities in the three leading countries in the field of broadband services. The lack of values between 100Mbps and 1000Mbps and the different approach by each country make the prediction process difficult.

Table 1 Broadband speed categories

	Cat 1	Cat 2	Cat 3	Cat 4	Cat 5	Cat 6
Digital Agenda	≥ 10 Mbps	≥ 30 Mbps	≥ 100 Mbps			
Sweden	≥ 10 Mbps	≥ 30 Mbps	≥ 100 Mbps	≥ 250 Mbps	≥ 500 Mbps	≥ 1000 Mbps
Romania	≥ 10 Mbps	≥ 30 Mbps	≥ 100 Mbps			≥ 1000 Mbps
Portugal	≥ 10 Mbps	≥ 30 Mbps	≥ 100 Mbps	≥ 400 Mbps		≥ 1000 Mbps

There are expectations that in the near future, common agreements will be reached among telecom operators, regulators, and the European Commission regarding standardized speed categories. This collaborative effort aims to establish consistent and agreed-upon criteria for categorizing broadband speeds across different regions. As per the current observations and the proposal put forth by the European Commission, the target speed category chosen is ≥ 1000 Mbps, aligning with the goals of the European Gigabit society[9].

Two econometric models are being considered to predict each parameter for the next speed category in each country with a minimum speed of 1000 Mbps. The candidate independent variables include service download speed, GDP per capita, and the share of DSL subscriptions in fixed broadband.

It is widely recognized that higher GDP per capita can lead to a more rapid adoption of services, as it serves as an indicator of welfare within each country. In this analysis, gross domestic product at purchasing power parity is chosen as it provides a better understanding of the impact on diffusion. Furthermore, the broadband speed performance is negatively impacted by DSL subscriptions, which depend on copper technology. This is due to the inherent technological limitations associated with copper-based infrastructure. Additionally, telecom operators may exhibit reluctance in offering contracts with speeds exceeding 100 Mbps, as the actual download speed experienced by users can significantly vary from the advertised service. Another crucial factor hindering service upgrades is the distance between the user's location and the nearest cabin. This distance presents significant obstacles, particularly for DSL connections, whereas fiber to the home (FTTH) infrastructure does not face such limitations.

It is expected that as the share of DSL subscriptions declines, the proportion of advanced speed categories will increase. Examining the results, a reliable regression model can be constructed for

the time shift coefficient using country fixed effects regression. However, challenges arise due to the limited number of observations (only 3 for each country), making traditional fixed effects models less suitable when incorporating multiple independent variables.

Furthermore, the coefficient that relates to the diffusion speed does not exhibit a consistent pattern across all countries. In such cases, taking an average from previous generations could be a reasonable assumption, particularly when the behavior displays similarity within a country and does not deviate significantly.

Once a reliable estimation is obtained for at least one of the two coefficients, a forecasting procedure can be generated for cases where initial adoption has already commenced. Illustrative examples will be presented for three countries, namely Romania, Sweden and Germany, where the adoption of Gigabit connections has reached significant levels compared to other European Union countries.

In Romania, it has been announced by the regulator ANCOM[10] that the adoption rate is already at 27% for the year 2022, positioning the country as a leader in this research domain. Sweden, on the other hand, has made significant progress in terms of adoption, with the diffusion pattern commencing approximately 10 years ago. The adoption rate for Sweden in 2022 stands at 7% as it has been announced by the regulator PTS[11]. Portugal and Spain exhibit similar adoption patterns to Sweden. However, their regulators have provided limited information, primarily focusing on the past two years. Despite this, the diffusion process in these countries is expected to follow a similar trajectory.

In cases where both coefficients are deemed reliable, it is possible to obtain a diffusion projection even without historical data. This indicates that with the estimated coefficients, it becomes feasible to forecast the adoption trajectory without relying on past observations.

Based on the analysis conducted and the discussions presented in the preceding paragraphs, preliminary results have been derived for the next data rate category. Following the evaluation of this category, it becomes possible to examine the migration from the previous categories and track their evolution until their eventual obsolescence. This can be achieved by making relevant deductions and drawing conclusions based on the corresponding values.

5. Results and discussions

The results of the regression analysis conducted on the diffusion models for the announced speed categories are presented in Tables 2 and 3. The coefficient pertaining to the diffusion speed is directly derived from the Logistic model. Conversely, for the time shift coefficient, the model that demonstrates better regression performance based on the R-squared metric was employed. A solver function was utilized to estimate the corresponding time at which 50% adoption occurred. Therefore, instead of presenting the actual value of the regression for this coefficient, we express it in terms of a year basis. For instance, the notation "2012.25" indicates the time period at the end of March in 2012, as per our assumption.

Table 2 Diffusion speed coefficient a

	>=100Mbps	>=30Mbps	>=10Mbps	Average	std
Germany	5.82	5.47	5.80	5.70	0.20
Italy	3.32	3.35	4.07	3.58	0.43
Hungary	4.33	4.58	3.66	4.19	0.48
Spain	2.90	3.84	3.49	3.41	0.48
Sweden	5.54	4.99	6.02	5.52	0.52
Slovakia	7.75	8.22	7.15	7.71	0.53
Croatia	3.49	4.64	4.25	4.13	0.58
Slovenia	5.06	4.26	5.51	4.94	0.63
Poland	4.31	5.61	5.04	4.99	0.65
Belgium	6.18	5.26	4.49	5.31	0.85
Portugal	4.18	5.00	3.27	4.15	0.86
Cyprus	1.89	3.62	3.32	2.94	0.93
Romania	5.40	7.20	6.97	6.52	0.98
Denmark	4.23	5.41	3.39	4.34	1.02
Luxembourg	3.97	6.20	5.47	5.21	1.14
Malta	3.76	3.18	1.51	2.82	1.17
Austria	5.50	6.65	8.02	6.72	1.26
Czechia	8.57	7.66	5.77	7.33	1.43
Netherlands	7.75	4.65	5.32	5.91	1.63
Ireland	7.39	5.25	4.11	5.58	1.66
France	5.23	5.96	2.64	4.61	1.74
Lithuania	7.13	9.05	5.39	7.19	1.83
Greece	1.86	4.35	5.77	4.00	1.98
Bulgaria	5.29	6.91	2.83	5.01	2.05
Estonia	7.75	7.68	3.95	6.46	2.17
Latvia	9.25	11.02	6.37	8.88	2.35
Finland	9.31	7.86	4.36	7.18	2.55

In the Table 2 the results sorted by purpose according to their standard deviation are displayed. The analysis reveals that Germany stands out as an exemplary case where the coefficient remains relatively consistent across all categories. Once an initial stream of data on adoption in the next category becomes available, it becomes feasible to make projections by incorporating the average value and allowing the time-shift coefficient to be captured through regression analysis.

However, this approach may not be applicable in cases such as Finland and Latvia, where significant variance exists between categories. In such instances, the variability between adoption rates necessitates a different approach for projection.

Table 3 Time shift coefficient b

	>=100Mbps	>=30Mbps	>=10Mbps
Austria	2024.9	2020.3	2014.9
Belgium	2018.1	2012.6	2010.4
Bulgaria	2023.1	2015.4	2009.4
Croatia	2023.8	2021.5	2016.9
Cyprus	2022.7	2021.4	2017.3
Czechia	2027.7	2018.5	2013.5
Denmark	2020.2	2016.6	2010.8
Estonia	2025.6	2019.6	2014.4
Finland	2022.8	2018.9	2012.6
France	2022.2	2021.1	2010.9
Germany	2023.5	2018.5	2013.5
Greece	2023.6	2022.3	2011.4
Hungary	2018.4	2015.9	2012.2
Ireland	2022.5	2015.2	2014.0
Italy	2020.9	2019.4	2016.9
Latvia	2016.8	2014.0	2011.9
Lithuania	2020.4	2014.0	2012.3
Luxembourg	2019.6	2016.4	2014.0
Malta	2020.6	2015.4	2012.5
Netherlands	2021.6	2014.8	2010.6
Poland	2020.0	2017.3	2014.3
Portugal	2017.4	2015.1	2009.8
Romania	2016.2	2013.3	2009.6
Slovakia	2025.3	2018.8	2015.5
Slovenia	2021.9	2019.2	2014.2
Spain	2018.8	2017.0	2012.3
Sweden	2016.3	2015.1	2011.1
Average	2021.3	2017.3	2012.9

Regarding the time-shift coefficient, Table 3 provides precise time periods at which the adoption reaches 50% for each category. Additionally, the average of all categories is included as an additional indication of the adoption pattern across the European Union. This allows for a comprehensive understanding of how the entire European Union is progressing in terms of adoption.

An econometric approach is now introduced to project the coefficients of the next speed category, focusing specifically on cases where the speed is equal to or greater than 1000 Mbps. In each row of the dataset, which will be utilized for regression analysis, the following variables will be included: country, diffusion speed of the category, time shift coefficient, download speed basis of the category (logarithmic transformation), share of broadband subscriptions based on copper or DSL technology at the time of 50% adoption, and GDP per capita at purchasing power parity (PPP).

The DSL share data was obtained from the digital agenda, and the actual values incorporated into the dataset were derived by applying a substitution effect. This effect accounts for the shift in the share of DSL subscriptions to other technologies, such as fiber to the home (FTTH), which is likely

to have occurred. It is noteworthy that each country previously reached a maximum share in DSL subscriptions, after which it began to decline. By considering this substitution effect, we are able to project future values when necessary. The data for GDP per capita were obtained from World Bank statistics[12].

The results of regression analysis for each coefficient, along with four different scenarios, are presented in Tables 4 and 5. Table 4 displays the findings for the diffusion speed coefficient a , while Table 5 pertains to the time shift coefficient b . Upon examining the results, it becomes evident that the performance in the first scenario, utilizing simple ordinary least squares (OLS), is weak in terms of explaining the variation in the diffusion speed coefficient. Only the DSL variable is found to be statistically significant, while neither GDP nor the speed category demonstrate a significant impact. The negative sign of the DSL coefficient prompts the question of whether a higher proportion of DSL subscriptions can truly facilitate a more rapid adoption of broadband subscriptions. This observation is noteworthy since smaller diffusion coefficients are typically associated with faster diffusion rates.

No evidence of multicollinearity was detected among the independent variables, as indicated by the variance inflation factor (VIF) values close to 1. In the second scenario, where OLS is again employed with only the DSL independent variable, the performance remains unsatisfactory, as indicated by the low R-squared metric and residual error. Moving on to the third scenario, country fixed effects were introduced alongside the DSL independent variable. However, the presence of multicollinearity is now more pronounced. It appears that the DSL variable exhibits a significant correlation with each country, despite the improvement in performance.

Furthermore, the fourth scenario involved testing a random effects model, wherein the sign of the DSL coefficient is closer to that observed in the OLS methods. However, the persistence of multicollinearity hinders the ability to make reliable projections.

Regarding the second case, the time shift coefficient has yielded reliable results. In the first scenario of ordinary least squares (OLS), only GDP did not demonstrate a significant impact on the volatility of the coefficient. Notably, DSL now exhibits a positive effect, indicating that a higher share of DSL subscriptions would result in a delay in the adoption of the next speed category. By excluding the insignificant GDP variable in the second scenario, more dependable and unbiased estimates were obtained. It is important to highlight the relative improvement in performance, as indicated by the R-squared metrics, in comparison to the diffusion speed case.

Moving on to the third scenario, country fixed effects were introduced alongside DSL and the speed category. Inevitably, the presence of multicollinearity arises, necessitating a transition to the fourth scenario, which involves fixed effects solely with the speed category. It appears that there may be other factors influencing the coefficient, warranting further investigation to elucidate the model's performance. DSL proved to be a challenging variable, as it can only be effectively utilized in simple OLS methods. The potential inclusion of other candidate independent variables may enhance the performance of the OLS scenario. Thus, the fourth scenario is the preferred approach, as the incorporation of unobserved heterogeneity in the fixed effect coefficients improves the regression performance compared to OLS.

Table 4 Regression speed diffusion a

	OLS					OLS			
	Estimate	Std. Error	t value	Pr(> t)	VIF	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	0.39	5.79	0.07	0.95		6.20	0.36	17.06	< 2e-16 ***
dsl	-0.03	0.01	-2.79	0.00665 **	1.09	-0.02	0.01	-2.82	0.00611 **
log(GDP)	0.51	0.58	0.87	0.39	1.29				
log10(cat)	0.30	0.55	0.54	0.59	1.27				
Country									
Residual error	1.80					1.80			
R-squared	0.11					0.09			
	Fixed effects					Random effects			
	Estimate	Std. Error	t value	Pr(> t)	VIF	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	10.74	2.42	4.43	4.78e-05 ***		6.30	0.50	12.61	<2e-16 ***
dsl	-0.07	0.04	-1.75	0.086479 .	37.50	-0.03	0.01	-2.32	0.0206 *
log(GDP)									
log10(cat)									
Country					37.50				
Residual error	1.33					1.33			
R-squared	0.67					0.50			

Table 5 Regression time shift coefficient b

	OLS					OLS			
	Estimate	Std. Error	t value	Pr(> t)	VIF	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	2011.79	7.71	260.78	< 2e-16 ***		2002.22	1.15	1743.18	< 2e-16 ***
dsl	0.06	0.01	4.60	1.63e-05 ***	1.09	0.05	0.01	4.41	3.26e-05 ***
log(GDP)	-0.98	0.78	-1.26	0.21	1.29				
log10(cat)	9.21	0.74	12.52	< 2e-16 ***	1.27	8.80	0.66	13.31	< 2e-16 ***
Country									
Residual error	2.40					2.41			
R-squared	0.71					0.70			
	Fixed effects					Fixed effects			
	Estimate	Std. Error	t value	Pr(> t)	VIF	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	2032.10	5.11	397.50	< 2e-16 ***		2007.49	1.21	1655.51	< 2e-16 ***
dsl	-0.35	0.07	-4.91	9.42e-06 ***	108.39				
log(GDP)									
log10(cat)	5.78	0.66	8.72	9.55e-12 ***	2.89	8.41	0.47	18.00	< 2e-16 ***
Country					106.50				
Residual error	1.43					1.72			
R-squared	0.93					0.90			

Next, a pilot projection will be demonstrated for Sweden and Romania, considering that the adoption of Gigabit service has already commenced. As previously explained, the time shift coefficient will be only utilized, while the diffusion speed will be estimated through regression analysis. Furthermore, a challenging forecast for Germany is conducted, taking into account the aforementioned observation of similar behavior in the diffusion speed across previous speed

categories. In this instance, the time shift coefficient will be captured through our analysis. In addition the previous methodology is applied for comparison reasons.

In Romania, the adoption of the Gigabit service has reached 27% by the end of 2022, as reported by the official regulator ANCOM. The compilation of Table 6 was based on the annual reports provided by ANCOM. This achievement places Romania among the leaders in high-speed broadband adoption within the European Union. According to our projection, the time shift coefficient is estimated to be 2025.69, corresponding to the month of August in 2025, when it is anticipated that 50% of broadband subscriptions will have connections of at least 1 Gbps.

Table 6 Penetration share of 1 Gbps service in Romania.

Data source: ANCOM

2020.5	2021	2021.5	2022	2022.5	2023
0.092	0.173	0.191	0.221	0.244	0.269

Figure 1 illustrates the 1Gbps adoption forecasting results for the three mentioned approaches. In the first case, referred as the "simple method," we project using a logistic function without applying any specific rules to the three coefficients of the function.

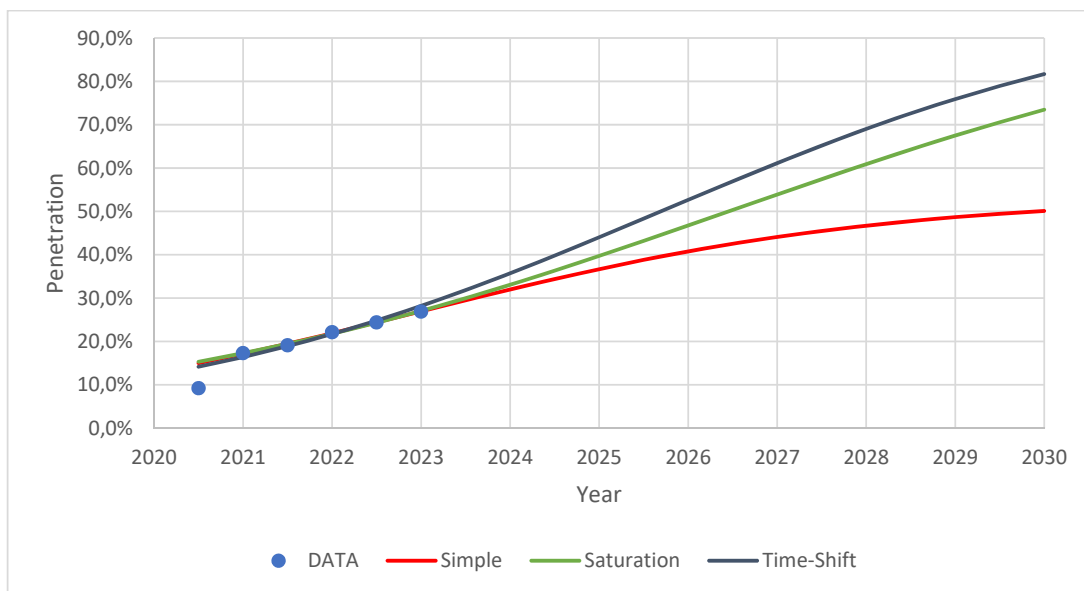


Figure 1 Forecasting 1 Gbps adoption in the case of Romania

In the second one, called as the "saturation method," a 100% saturation rule is applied. Eventually, following the methodology presented, we combine the 100% saturation rule with setting the time shift coefficient to August 2025, which is referred as the "Time - Shift method." The diffusion speed was determined to be 5.76 through regression, presenting a reasonable estimation that takes into account the previous speed categories, as evidenced in Table 2.

Figure 2 depicts the evolution between speed categories, taking into account the relevant deductions between successive speed categories (i.e. speed category 10-30 Mbps is calculated by subtracting the diffusion sequence of 30 Mbps from 10 Mbps), in the case of Romania.

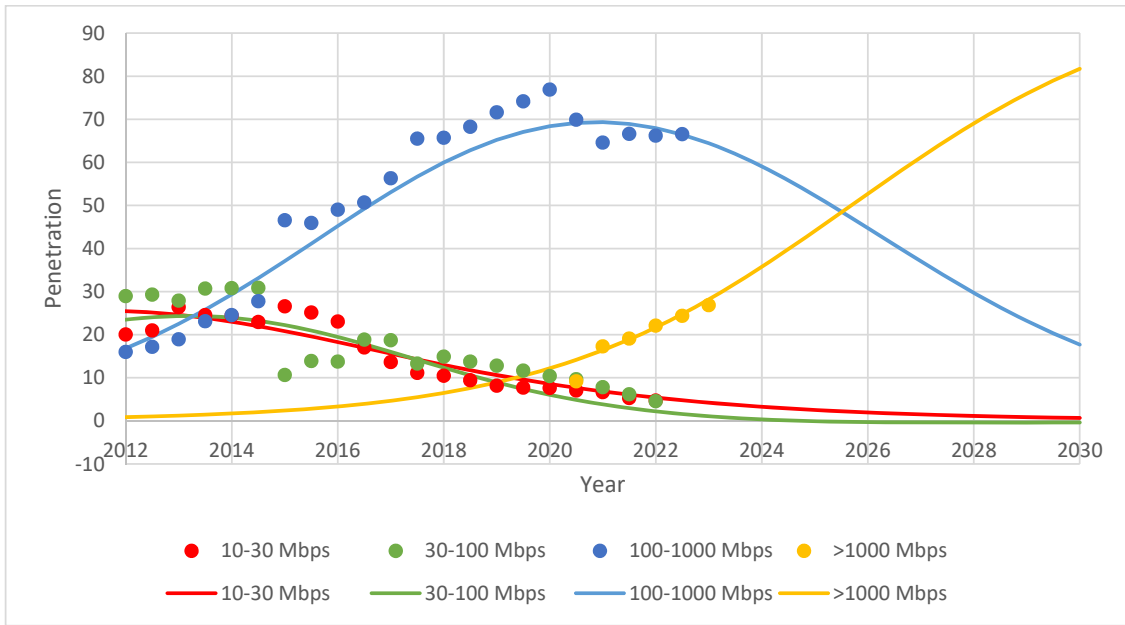


Figure 2 Forecasting Gigabit adoption and the evolution between speed categories in Romania (relevant deductions are taken into account)

In Sweden, the adoption of the Gigabit service has reached approximately 7% by the end of 2022, as reported by the official regulator PTS in Table 7. The compilation of Table 7 was based on the portal statistics provided by PTS, with data from 2019. Existing data for previous years have been omitted due to their insignificant values. Despite this, in Figure 3, the initial adoption of the Gigabit service can be observed from 2013.

Table 7 Penetration share of 1Gbps service in Sweden.

Data source PTS

2019	2019.5	2020	2020.5	2021	2021.5	2022	2022.5	2023
0.029	0.033	0.036	0.043	0.051	0.053	0.056	0.062	0.067

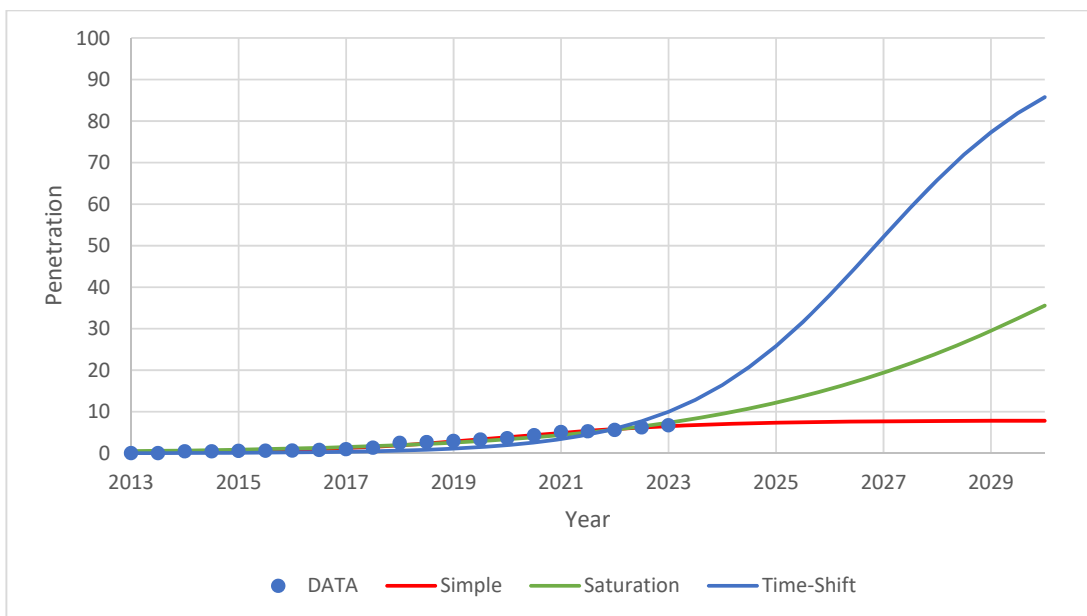


Figure 3 Forecasting 1Gbps adoption in the case of Sweden

Figure 3 presents the 1Gbps adoption forecasting results for the three approaches, similar to the case of Romania. Based on our projection, the time shift coefficient is estimated to be 2026.852, which corresponds to the month of October in 2026.

In both cases, without applying the saturation rule, the forecast appears to be overly pessimistic due to the early stage of adoption. However, after setting the saturation level to 100%, a reliable projection is obtained for Romania, whereas for Sweden, the projection remains somewhat pessimistic. When the time shift is applied in Sweden, the diffusion speed obtained from regression is approximately 3.5, whereas previous generations had a coefficient of around 5. In this case, our projection could be considered slightly optimistic. The better outcome in the case of Romania can be attributed to the higher maturity of broadband adoption in the country, currently standing at a rate of 27%. Additionally, the regression result for Sweden takes into account a greater number of past observations (negligible valued at majority), which is likely to influence the outcome.

In the case of Germany, the adoption of Gigabit service by the end of 2022 was observed to be 5.3% according to Bundesnetzagentur[13]. A review of Table 8 reveals data for the years spanning from 2019 to 2022. The compilation of Table 8 was based on the annual reports provided by Bundesnetzagentur. In order to project future trends, the stable diffusion speed coefficient of 5.7, derived from previous speed categories, is utilized. Additionally, an estimated time shift coefficient of 2031.203 is incorporated. Five scenarios are employed for comparative analysis.

Table 8 Penetration share of 1Gbps service in Germany.

Data source: Bundesnetzagentur

2020	2021	2022	2023
0.006	0.028	0.038	0.053

The methodologies previously applied to Romania and Sweden are considered, along with a relative approach focusing solely on the diffusion speed. Lastly, a final approach is utilized, encompassing all predetermined coefficients. With this approach, predictions can be generated without reliance on any data, even for previous years if our methodology were in existence. The results indicate a remarkable similarity among the three latter approaches in their projections for 2030. The projection for Germany is depicted in Figure 4.

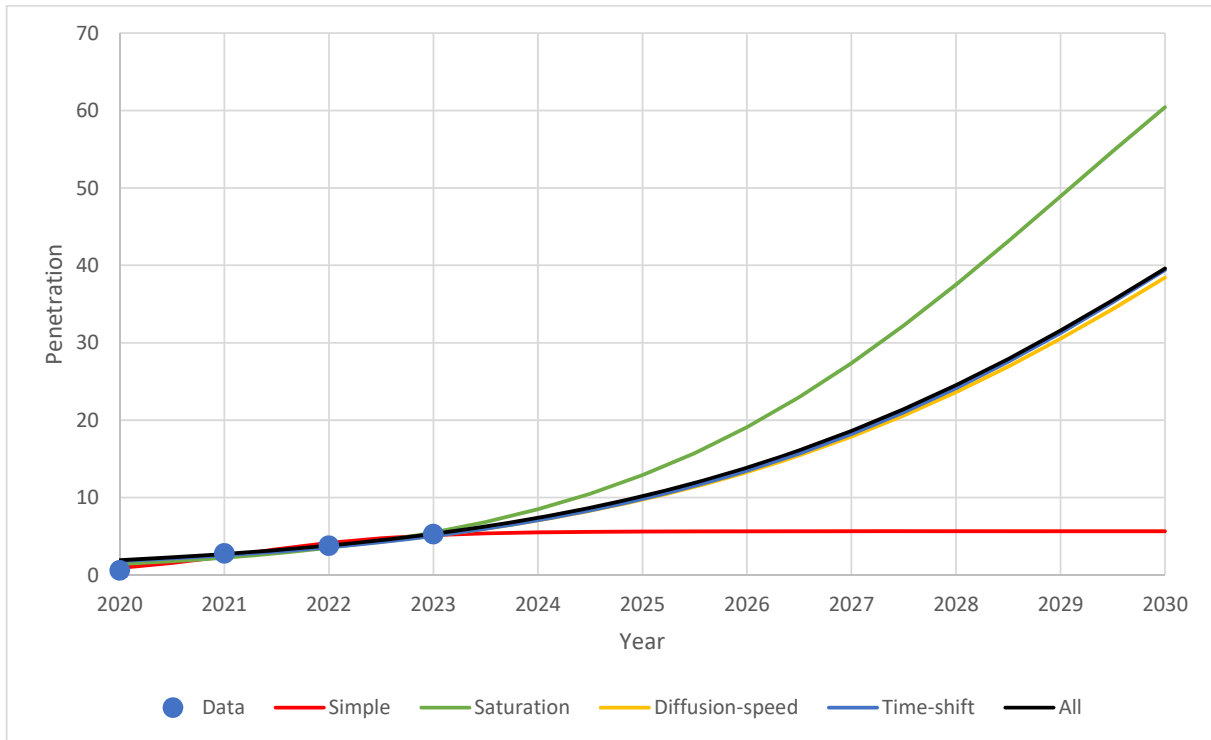


Figure 2 Forecasting 1 Gbps adoption in the case of Germany

In the case of Germany, the predictions of all three last methods are almost identical. This fact, combined with the satisfactory estimation of the diffusion- speed coefficient α , reinforces our belief in a particularly effective forecast.

In Germany, there is a remarkable adoption of Gigabit service compared to Sweden. However, the adoption of speeds higher than 100 Mbps is not as mature in Germany, primarily due to a higher share of the DSL technology in the broadband market.

6. Conclusions

Based on the obtained preliminary results by our methodology, it is obvious that the inclusion of additional independent variables in future studies could enhance the forecasting performance. Besides, the DSL share proved to be an interesting independent variable; however, it was unable to effectively cooperate with country fixed effects due to the presence of multicollinearity.

The results indicate that the countries that heavily relied on copper infrastructure in the past face challenges in transitioning to high-speed broadband services. This is evident in countries such as Greece, Cyprus, Germany, Italy, Croatia, and France, where their impact on subscriptions of at least 100 Mbps is relatively small. However, it is noteworthy that Greece and Cyprus exhibit a significantly high diffusion speed for the 100 Mbps and higher speed category. This suggests that countries that initially lagged behind in adopting new technologies may experience an accelerated adoption rate in later stages, potentially compensating for the initial delay.

Significantly, no notable impact was observed in the predictability of future high-speed broadband subscriptions by GDP per Capita. The prevailing assumption was that countries with higher income would receive superior services compared to those with lower income. However, if a significant correlation had emerged, it would not have accounted for the phenomenon wherein countries like

Latvia, Lithuania, Bulgaria, and Romania, for instance, experience better services than more developed nations such as Germany and France.

In future research endeavors, it is imperative to explore alternative methodologies to address the limitations encountered in the regression analysis. Other approaches, such as machine learning techniques, have been employed in similar studies on pre-launch forecasting. These alternative methods may provide valuable insights and overcome the challenges faced in the current analysis.

References

- [1] R. J. Thomas, “Estimating market growth for new products: An analogical diffusion model approach,” *J Prod Innov Manage*, vol. 2, no. 1, pp. 45–55, Mar. 1985, doi: 10.1016/0737-6782(85)90015-3.
- [2] R. K. Srivastava, V. Mahajan, S. N. Ramaswami, and J. Cherian, “A multi-attribute diffusion model for forecasting the adoption of investment alternatives for consumers,” *Technol Forecast Soc Change*, vol. 28, no. 4, pp. 325–333, Dec. 1985, doi: 10.1016/0040-1625(85)90034-4.
- [3] H. Gatignon, J. Eliashberg, and T. S. Robertson, “Modeling Multinational Diffusion Patterns: An Efficient Methodology,” *Marketing Science*, vol. 8, no. 3, pp. 231–247, Aug. 1989, doi: 10.1287/mksc.8.3.231.
- [4] R. M. Heeler and T. P. Hustad, “PROBLEMS IN PREDICTING NEW PRODUCT GROWTH FOR CONSUMER DURABLES.,” *Manage Sci*, vol. 26, no. 10, pp. 1007–1020, Oct. 1980, doi: 10.1287/mnsc.26.10.1007.
- [5] H. Lee, S. G. Kim, H. woo Park, and P. Kang, “Pre-launch new product demand forecasting using the Bass model: A statistical and machine learning-based approach,” *Technol Forecast Soc Change*, vol. 86, pp. 49–64, Jul. 2014, doi: 10.1016/j.techfore.2013.08.020.
- [6] P. Yin, G. Dou, X. Lin, and L. Liu, “A hybrid method for forecasting new product sales based on fuzzy clustering and deep learning,” *Kybernetes*, vol. 49, no. 12, pp. 3099–3118, Jan. 2020, doi: 10.1108/K-10-2019-0688.
- [7] “Key Indicators — Digital Scoreboard - Data & Indicators.” https://digital-agenda-data.eu/datasets/digital_agenda_scoreboard_key_indicators/visualizations (accessed Jun. 12, 2023).
- [8] K. Petre and D. Varoutas, “On the application of Machine Learning in telecommunications forecasting: A comparison,” 2022, Accessed: Dec. 22, 2022. [Online]. Available: <https://www.econstor.eu/handle/10419/265665>
- [9] European Commission, “Support for Broadband rollout.” <https://digital-strategy.ec.europa.eu/en/policies/broadband-support> (accessed Jun. 09, 2023).
- [10] “Autoritatea Națională pentru Administrare și Reglementare în Comunicații - Infomații Publice.” <https://statistica.ancom.ro/sscpds/public/alldocuments/report> (accessed Jun. 10, 2023).
- [11] “Statistikportalen.” <https://statistik.pts.se/en/the-swedish-telecommunications-market/tables/internet-services/table-24-subscriptions-broadband/> (accessed Jun. 09, 2023).
- [12] “GDP per capita, PPP (current international \$) | Data.” <https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD> (accessed Jun. 10, 2023).
- [13] “Bundesnetzagentur - Mediathek.” https://www.bundesnetzagentur.de/DE/Allgemeines/Presse/Mediathek_3/start.html (accessed Jun. 10, 2023).