ECONSTOR Make Your Publications Visible.

A Service of

ZBW

Leibniz-Informationszentrum Wirtschaft Leibniz Information Centre for Economics

Pápai, Zoltán; Nagy, Péter; McLean, Aliz

Conference Paper Quality-adjusted price changes on the Hungarian mobile market between 2015-2021

31st European Conference of the International Telecommunications Society (ITS): "Reining in Digital Platforms? Challenging monopolies, promoting competition and developing regulatory regimes", Gothenburg, Sweden, 20th - 21st June 2022

Provided in Cooperation with:

International Telecommunications Society (ITS)

Suggested Citation: Pápai, Zoltán; Nagy, Péter; McLean, Aliz (2022) : Quality-adjusted price changes on the Hungarian mobile market between 2015-2021, 31st European Conference of the International Telecommunications Society (ITS): "Reining in Digital Platforms? Challenging monopolies, promoting competition and developing regulatory regimes", Gothenburg, Sweden, 20th - 21st June 2022, International Telecommunications Society (ITS).

This Version is available at: https://hdl.handle.net/10419/265663

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.



WWW.ECONSTOR.EU

Quality-adjusted price changes on the Hungarian mobile market between 2015-2021

Zoltán Pápai, ¹ Péter Nagy, ² Aliz McLean³

Paper to be presented at the International Telecommunication Society Conference 2022

Abstract

Mobile technology and services have developed dramatically over the past decades, with mobile operators' competing commercial offers providing a wide menu of service packages with varied quality and quantity characteristics. The prices of these commercial offers do not directly reflect the continuous improvements in service characteristics and functionalities over time: the price changes need to be adjusted for quality. In this paper, we estimate the hedonic changes in residential mobile consumer prices on the Hungarian market by controlling for the changes in the relevant service characteristics and quality, between 2015 and 2021. We also attempt to separate the hedonic price changes from the effect of two specific government interventions that occurred in Hungary, namely the changes in the value added tax (VAT) levied on internet services, in 2017 and 2018. Our results show significant hedonic price changes over the observed period of over 30%, which turns out not to be primarily driven by the VAT policy change, but by real improvements in broadly defined service quality.

Keywords: hedonic regression, mobile prices, mobile telecommunications, Hungary

¹ Infrapont Economic Consulting, email: <u>zoltan.papai@infrapont.hu</u>

² Infrapont Economic Consulting, email: <u>peter.nagy@infrapont.hu</u>

³ Infrapont Economic Consulting, email: <u>aliz.mclean@infrapont.hu</u>

1. Introduction

Mobile technologies and services have developed significantly over the past decades. Today, competing mobile operators provide voice, messaging and broadband data via a wide menu of commercial offers with varied qualitative and quantitative characteristics. Simply comparing the prices of commercial offers over time does not reflect the continuous improvements in service characteristics and functionalities. Only quality-adjusted price changes can provide adequate information on the evolving value of these services.

The main motivation and goal of this paper is to estimate the hedonic changes in residential mobile consumer prices on the Hungarian market by controlling for the improvements in the relevant service and quality characteristics, between 2015 and 2021. A secondary goal of the study is to separate the truly hedonic price changes resulting from service development and competition from the effect of the government tax interventions that occurred in the middle of this period.

After the shock of the 2008 economic crisis, there came a period of low inflation in developed countries. This also stands for Hungary, where the heavy-handed government policy of freezing energy prices and other public utility and communal service charges was an additional factor in tuning inflation down. In the second half of the 2010s, however, unregulated consumer prices started to increase. According to the Hungarian Statistical Office, the consumer price index was 18.6% higher in 2021 compared to 2015, and this increase was 11% in the service price index. In contrast, telecom consumer prices (which are not regulated) decreased by a little more than 7% over this period.⁴ One of the drivers of this perceived price decrease was most certainly the reduction of the value added tax (VAT) rate on internet services (both fixed and mobile), due to the government's intention to promote digital service take-up and usage. In two steps, the 27% VAT rate⁵ was reduced first to 18% in 2017 and further to 5% in 2018 for internet services, while the VAT on voice and text messaging (SMS) services remained at its original 27% level. Since then, while users of bundled voice and data packages pay a single price for the package, the tax content of the voice and the data parts has become different.

In addition to the change in VAT, there may well be other drivers behind the price decrease, like competition or cost efficiencies passed on to consumers. The official statistical index masks these effects. Moreover, the official aggregate index does not take into account the considerable increase in quality in mobile services (as a result of extensive 4G network deployments), nor the improvements in quality and quantity in the characteristic features of mobile services. For products and services where quality characteristics improve from year to year, conventional statistical price indexes (which do not control for these changes)

⁴ The Hungarian Statistical Office publishes only a common price index for telephony and internet services, not separating voice telephony (including SMS services) and internet services, nor fixed and mobile services. The regulator also does not provide such figures.

⁵ The general VAT rate in Hungary was raised from the already high 25% to 27% in 2012, making it the highest general consumption tax rate in Europe.

are almost useless: they cannot function as good proxies for measuring the changes in consumer welfare. Hedonic indexes are the correct instruments for this job.

In this study we assess the cumulative quality-adjusted price changes of mobile services in Hungary. We use the hedonic regression methodology to estimate quality-adjusted changes in mobile prices for residential postpaid mobile packages between 2015–2021. First, we show the trajectory of quality-adjusted price changes in the studied period, and second, that the estimated price decrease is significant even if we take the two-stage VAT decrease of 2017-18 into account.

The structure of the paper is the following. Section 2 discusses the background of the hedonic approach, and specifically the time dummy variable hedonic regression method. Section 3 provides a fairly detailed literature review of applying the hedonic approach to mobile telecom pricing. Section 4 briefly presents developments on the Hungarian mobile market between 2015 and 2021. Section 5 describes our data and Section 6 our modelling considerations. Section 7 details our results, and Section 8 concludes.

2. The hedonic approach

Mobile services are complex: the packages contain many different service elements and features, but are priced as bundles. To assess the improvement in consumers' position, it is not enough to focus on the price of the mobile service – which often does not change or even increases. Any meaningful comparison must consider that the quality and/or the service content is improving, and the quantities of data, voice and messages included are increasing. Hedonic analysis is a well-established method for identifying and measuring quality-adjusted price changes. In this paper, we analyse these quality-adjusted mobile prices in Hungary between 2015–2021, by estimating a chain of hedonic price indices. We use a hedonic function to relate the prices of different varieties of a product and the quantities of various characteristics in them (see Triplett, 2004, 41).

A mobile plan typically consists of many individual service characteristics and features, and the bundle of these quantity and quality characteristics determine the price of the total. According to the hedonic approach, the utility from the consumption of the product or service stems from these characteristics. Hedonic pricing assumes that the total price of a product is the sum of the prices of the individual characteristics. Product characteristics may change over time; in the case of technological products (like computers or mobile phones) or services (like mobile or fixed communication), quite quickly. We may therefore experience significant changes in the quality and/or quantity characteristics, while the observed product price remains relatively stable, rendering conventional price indexes essentially useless.

The adequate hedonic index can be calculated in several ways, for example by using the dummy variable method, the product-specific price index, or by using indirect solutions such as a hedonic imputed price or hedonic quality adjustment methodologies (Triplett 2004).

The use of a hedonic index and a hedonic function in economic analysis is not new. The theoretical foundation of the hedonic approach was laid down by Kelvin Lancaster (1971) in

his consumer theory. His main assumption is that each product can be interpreted as a set of different consumption characteristics, and consumers buy the product because of the utility gained from these. Another important contribution came from Rosen (1974), who described the economic theoretical framework for the hedonic analysis, linking it to product differentiation, which is found in many industries. Instead of looking at differentiated products as many goods that are somewhat different from each other, they can be interpreted as combinations of a few product characteristics. The correlations between price and the realised combination of these characteristics can be studied empirically using the hedonic method.

As Triplett (2004, 87-89) discusses in a historical note, there were empirical studies we would now call hedonic even before the appearance of the theory. He mentions Court (1939), Stone (1956) and Griliches (1961) to be the pioneers of applying the dummy variable method for estimating hedonic price indexes. Griliches was the first to use other than dummy variable methods in his econometric studies of the used car market (see Griliches1961 and Ohta and Griliches 1976).

Here we describe only the essence of the dummy variable method, which is used frequently and which we also chose to study the changes in mobile prices.

2.1 Time dummy variable hedonic regression method

In the time dummy variable hedonic method, we run a regression of the product prices on the relevant service characteristics, and a separate dummy variable is included in the model to capture the time effect. This method is also called the direct method because the time dummy variable coefficient directly measures the price change that has occurred in the given period compared to the base period. The price change of several consecutive periods can be calculated as a chain index by adding the coefficients of the subsequent periods.

In the estimation, together with the time dummy variable, we also estimate the coefficients of the relevant product characteristics. These coefficients are also informative in themselves, but first and foremost we are using them to filter out the effects of changes in the product characteristics, in order to get a good estimate of the time coefficient. This coefficient then measures the quality-adjusted price change over the given period.

The other estimated coefficients of the regression can be considered the implicit prices of the service characteristics. They give the effect of the change in these characteristics on the price, keeping the other factors fixed.

The hedonic function is the following (see de Haan and Diewert (2013):

$$p_i^t = f\left(z_{i,1}^t, \dots, z_{i,K}^t\right)$$

where:

 p_i^t is the price of product *i* in period t; t = 0, ..., T,

 $z_{i,k}^{t}$ is the *k*th characteristic of product *i* in period t; k = 1, ..., K.

The general form of the linear time dummy variable regression equation is the following:

$$p_i^t = \alpha + \sum_k \beta_k * z_{i,k}^t + \delta^t * d^t + \varepsilon_i^t$$

where:

 α is the constant,

- β_k is the coefficient of the *k*th characteristic of the product (implicit price),
- d^{t} is the dummy variable in period t (equals to 1 in period t, and 0 otherwise);
- δ^t is the coefficient of the time dummy (price change in period *t*),
- ε_i^t is the error term of product *i* in period *t*;

For the correct model specification, it is important to include in the equation all relevant product or service characteristics in order to avoid the omitted variable bias. Parameters can simply be estimated using ordinary least squares (OLS).

3. Review of the literature: the hedonic approach in analysing mobile prices

The use of the hedonic approach to study changes in telecom prices is a relatively recent enterprise. There have been only a few studies on the hedonic prices of mobile services so far; with most articles being published from 2010 onwards. However, we present a fairly detailed review of the studies that are available, in order to make them comparable with each other and with our own study.

The earliest substantive study was undertaken by Karamti and Grzybowski (2010). They examined the evolution of hedonic mobile prices in France from June 1996 to December 2002. The authors compiled monthly data on postpaid and prepaid offers from telecom price magazines and annual reports from the French regulatory authority, ARCEP.

The database recorded the characteristics of 3022 tariff packages in three main groups. The first group contained basic features, such as the minutes included, the intensity of the usage and the name of the service provider. The second group was made up of horizontal or value-added service features, like call forwarding. And finally, the third group contained the technical parameters of the network, such as coverage.

Karamti and Grzybowski (2010) used a time dummy variable hedonic regression model and estimated the coefficient of price change for pairs of adjacent months. According to the specification of the model, the dependent variable was the logarithm of the price, and the independent variables were mostly category variables.

Since there was no information on the number of users for the observed packages, they could not assign weights to the price observations. Coefficients were estimated by OLS regression.

The trajectory of price change was calculated by cumulating the estimated monthly price changes. Prepaid and postpaid offers were regressed separately, and although in both cases hedonic price declines were measurable throughout the period, monthly prices varied over time and to differing degrees. A separate estimate was done for each provider and the

authors tested whether the changes had followed different dynamics for the different providers.

This pioneering hedonic study was carried out at an early stage of the mobile market. This was the period of extensive development when mobile service penetration was far from full, and residential mobile data services were practically non-existent. Many of the differentiating characteristics that were important at the time of the study and seemed essential to incorporate into the hedonic function have now become less important or even marginal, and have lost their relevance as differentiating factors.

In spite of this, we believe that the study is still important because it was the first to demonstrate the relevance and usefulness of the hedonic approach for studying mobile prices. In addition, two methodological lessons are worth highlighting: (1) the hedonic analysis can be performed on an unbalanced panel on publicly available mobile offers without consumption weights, and the results will still be informative about price level changes; (2) the problem of multicollinearity (due to the connection between the relevant characteristics) can be mitigated well by combining the correlating service characteristic variables into composite variables.

Almost a decade later, Nicolle, Grzybowski, and Zulehner (2018) conducted another hedonic mobile price study in France. They analysed the price changes of mobile packages between May 2011 and December 2014. They investigated mobile prices in a quite different period then the Karamti-Grzyboski study. This time it was the era of mature 3G when smartphone penetration was increasing significantly and smartphones were starting to dominate the market. In this period, most of the mobile plans incorporated a low but growing amount of data usage beside the usual voice and SMS services.

The authors had data on the offers of Orange, the largest network operator on the French market. However, they claimed that their results may well also reflect the price dynamics of the whole market, since the prices of the competitors correlated strongly with those of the market leader. In the nearly four-year period under review, 1112 tariff packages were identified, resulting in a total of 7346 monthly tariff observations.

The service characteristics they considered were the size of the data allowance, the amount of voice minutes included in the package, whether the offer was a part of a quadruple play bundle, the loyalty contract, the device subsidy, the 3G discount (low-cost plan), and premium access to music (Deezer). Most of the variables in the hedonic equation were category variables. They used the numbers of monthly customers, from the panel subscriber database of Orange, as quantity weights for the observations.

The dependent variable of the hedonic equation was the price of the plan in euros, and the explanatory variables were the package characteristics. The estimation was done on the pooled data, so the month dummy coefficients they obtained measured the estimated cumulative price change to the base period, and the trajectory of the price change was defined by these estimates. The authors estimated their models by OLS and also by weighted least squares (WLS) using the subscriber numbers as weights. The OLS estimate

showed a lower price decline than the WLS estimate, though the latter fit better and they also considered its output more realistic.

The cumulative quality-adjusted price change was estimated as -42.8%, quite remarkable concerning the relative shortness of the period. It is not surprising that the decrease was significantly larger than the -8.7% cumulative change of the average price, which was calculated without controlling for the changes in the service characteristics.

A further, relatively recent hedonic study of mobile prices was prepared by OFCOM (2018), the UK telecom regulator. They conducted an econometric analysis of mobile price developments in the UK between 2013 and 2017 using hedonic regressions. Their analysis was motivated by the need to investigate the validity certain publicly raised concerns on mobile pricing in the UK.

In the period OFCOM studied, significant changes occurred in service characteristics: for example, the 4G service was launched and rolled out quickly, and as a result service quality characteristics improved significantly. Packages' data allowances as well as the volume of calls and messages included in the plans increased.

OFCOM investigated mobile service provider offers in the UK between 2013 and 2017. The database contained more than 1.2 million monthly observations. There was no available data on the number of users for each package, therefore it was not possible to assign consumption weights to the different observations. However, OFCOM had data on the devices and their characteristics, which were available in connection to some of the plans.

The dependent variable of the model was the monthly fee, in GBP. The service characteristics in the hedonic model were: device category; contract length (loyalty period); data, voice and SMS allowance included in the package; network technology (3G or 4G) and service dummies. Some model specifications used year-provider interactions.

Two model specifications were used. The first model used the linear specification which was preferred as a result of the Box-Cox test, the other used a linear-log specification, where a logarithmic transformation was applied to the data allowance. Overall, they found that the use of different specifications did not lead to a significant difference in results.

The estimation was done on pooled data. The robustness of the results was tested by using alternative variables and variable specifications, but these did not cause significant change in the results. From the main models, data on packages with greater than 20 GB data allowances were left out. They focused only on postpaid packages.

OFCOM found that the estimated cumulated quality-adjusted price of mobile services decreased by GBP 6 from 2013 to 2017. In addition to the general price change in the market, they also looked at how the price change developed by service provider and found that there were significant differences between the operators.

In addition to these three studies, we mention two others briefly.

Forenbacher, Perakovic and Husnjak (2016) studied the changes in the prices and quality characteristics of mobile packages in Croatia between 2009-2013, using hedonic analysis.

They compiled the database from public data on the monthly fees and service characteristics of a total of 249 postpaid packages for the whole period. Most characteristics were coded as dummy variables. A network operator dummy was also used to capture provider-specific fixed effects.

They tested two model specifications, simple linear and log-linear versions. The linear specification was found to fit better. They estimated the time dummies with OLS on the pooled database, however an estimation on pairs of adjacent periods was also done. As data on the number of consumers for each package was not available, they could not assign weights to the observations. Based on the results of the linear model and the average price of the starting period, they calculated a hedonic price index. However, the small number of annual observations set a substantial limit on the number of variables they could afford in the model, and the magnitude of the standard errors constrained the inference, rendering their results rather exploratory. The main virtue of the study was, however, to demonstrate the applicability of the hedonic method even for a small dataset with a limited number of observations.

Finally, Kim and Kim (2018) conducted a hedonic study on the South Korean mobile market, in which they examined the tariff packages of three operators between 2010 and 2017. They collected their data from the new offers that appeared on the service providers' websites year by year. Then they created the database containing annual data by using the assumption that a new package lives on the market for 3 years, then disappears. From the total of 209 different offers, a database of 744 observations was produced as a result. In addition to the price, the database also contained information on the important characteristics of the mobile packages.

They used time dummy hedonic regressions to estimate the hedonic price change with loglinear and log-log specifications. They also applied observation weights which were derived from combining the market share of the operators and the information on consumer expenditures from market research. They estimated the models with WLS for each pair of adjacent years.

They calculated an annual average hedonic price change of -8.1% for the observed period. Individual changes by operator were different, but around this number. The price index obtained from the log-log model was compared to the standard price index, and the authors concluded that the change in consumer welfare was better reflected by a hedonic than by the standard index.

4. Developments on the Hungarian mobile market between 2015-2021

The voice segment of the three-player Hungarian mobile market had reached maturity by 2015. The penetration rate was around 110% during the entire 2015-2021 period, and most of the basic characteristics of the market remained unchanged, except for the postpaid/prepaid ratio. The share of postpaid customers increased continuously from 57.6% in the last quarter of 2015 and exceeded 70% by the end of the period.

Figure 1. Growth of the mobile and mobile internet user base between 2015 - 2021



Source: NMHH (National Media and Communications Authority)

In contrast to mobile voice, there have been significant changes in mobile internet services during this period. The deployment of 4G networks started in 2011, but 4G coverage (in terms of households) was only at 40% in 2013, far below the EU average (then 60%). 4G network development significantly accelerated after the auction of the 800 MHz digital dividend in 2014, however. Over the next year, two network operators, T-Mobile and Telenor agreed on an MOCN sharing of their 800 MHz network outside the capital, Budapest, which significantly hastened the deployment. As a result, almost complete national network coverage (98,6%) was reached by the end of 2016, far above the EU average.

The figure below shows that an increasing share of internet traffic migrated from legacy technologies to the new 4G networks, and exceeded 90% of total mobile data traffic by 2018.

Figure 2. Share of the technology generations in the mobile data traffic between 2015 - 2021



Source: NMHH (National Media and Communications Authority)

In the meantime, total mobile data traffic grew significantly from less than 10 Petabytes in the second quarter of 2014 to above 200 Petabytes by the second quarter of 2021. The monthly data traffic per postpaid SIM card increased from 0.7 GB to 8.1 GB from the end of 2015 to mid-2021.

Figure 3. Growth of the voice and data traffic between 2015 - 2021



Source: NMHH (National Media and Communications Authority)

On the demand side, mobile broadband penetration increased dynamically due to the expansion of the small screen segment, while the number of large screen subscribers stagnated. Nevertheless, both segments showed significant growth regarding traffic per

user. Furthermore, international mobile internet usage (i.e. mobile data roaming) increased significantly after the introduction of the new EU roaming regulation in 2017.

The main structural characteristics of the Hungarian mobile market structure remained essentially unchanged during the period. The market shares of the three MNOs – all subsidiaries of large international mobile operator groups – remained stable: T-Mobile was the market leader with a market share around 45%, followed by Vodafone and Telenor⁶ with similar shares (around 27% each). MVNOs never achieved significant shares, nor played a significant role on the Hungarian mobile market, indeed their small market share even diminished during the period.

In the meantime, it came as a small shock to the incumbents when Digi – an aggressive player on the fixed telecom and pay TV market – acquired spectrum in 2016 at the auction for the 1800 and 3500 MHz bands and started to build its own network. The new entrant failed to accumulate enough spectrum on the subsequent auctions, however.⁷ Although Digi launched its commercial mobile services in 2021, it now seems clear that its limited spectrum assets will not enable it to become a fully-fledged challenger to the three incumbent MNOs on the mobile market (see NMHH 2021).

In 2017 and 2018, a significant government intervention occurred in two steps: the Hungarian government decreased the VAT on the internet (but not the voice and messaging) services, with the goal of stimulating an increase in internet penetration and usage. The 27% VAT rate was reduced to 18% in 2017, and further to 5% in the next year. This selective consumption tax reduction decreased the price of data only and combined voice and data packages, and also changed the relative prices of voice/SMS versus data.⁸ It was an exogenous non-transient intervention, to which both the suppliers and the customers adapted. Since then, the high VAT difference between voice/SMS and data has become the new normal.

5. Data

For this study, we prepared a dataset on the postpaid residential tariff plans of the three Hungarian MNOs (T-Mobile, Vodafone, Telenor) for the 2015-2021 period. We collected the data from the operators' publicly available general terms and conditions documents. The database contains information on the price and various service features of both the basic and the optional, supplementary packages which were available to new subscribers in the last quarter of each year.

We included all the basic packages and discounts which were available to anyone without further restrictions. Therefore, the database does not include special tariff plans (e.g. for seniors, juniors, disabled people, etc.) or discounts offered for special customer segments

⁶ Telenor sold its Hungarian subsidiary to Cetin, but the company used the Telenor brand until 2022.

⁷ Digi was banned from participating in these auctions by the regulator, on the basis of regulatory compliance issues.

⁸ There is even a further twist regarding the relative prices, since another price distortion between voice/SMS exists in Hungary. Since 2012 there is a special unit tax (telecom tax), levied on voice and SMS usage, which according to the government prescriptions cannot be passed directly on to the consumers by the operators. Of course, indirectly this still pushes prices up.

(e.g. multiplay package discounts for fixed customers). Since there was no consistent information available on handsets and related discounts, these options were also left out of the database.

The majority of the plans are small screen packages with both data and voice/SMS usage. Large screen (data only) packages are also included in the database, which contains 211 basic packages altogether.

We recorded all main features of the packages which could have an impact on the price. The recorded features are the following:

- basic identifiers: year, operator, type of service (small/large screen), name of the tariff plan;
- factors which have a direct impact on the subscription fee: length of the contract (loyalty period), "e-discount" (provided if the costumer uses electronic invoices and payment);
- monthly subscription fee with VAT (with the applicable discounts), gross price of the data (internet) part of the package (which was available from 2017, when different VAT was applied to the voice/SMS and the so-called internet services);
- voice and SMS usage features: monthly voice minute or SMS allowance in different directions (on-net, off-net), unlimited usage, price per minute and per SMS;
- data usage features: monthly data allowance, unlimited usage, EU roaming data allowance, maximum up- and download speed;
- unlimited thematic data usage features: several packages include so-called unlimited thematic data usage. This is also known as a zero-rating service in the industry, when the traffic related to certain contents or applications does not count towards the general data allowance. We identified six unlimited thematic data usage types: social media, chat, navigation, browsing, music, and video.

In addition to basic tariff plans, our database also contains information on the packages or options which were available to the subscribers as supplements to certain or all basic packages. We recorded four types of supplementary packages: extra data, extra voice or SMS usage above that included in the basic package, and supplementary unlimited thematic data usage.

Our final database contains all possible combinations of basic packages and the available supplementary packages. Every combination can be deemed a separate independent package, and these represent our observations. Altogether we have 18 182 observations, the yearly distribution of which is shown in Table 1 below.

Table 1. The distribution of the observations

	2015	2016	2017	2018	2019	2020	2021
Large screen	94	172	111	75	123	121	100
Small screen	5026	5029	2481	1794	1082	924	1050
Total	5120	5201	2592	1869	1205	1045	1150
of which basic packages	39	38	29	24	25	26	30

6. Modelling considerations

6.1 Variables used in the model

Our dependent variable is the monthly subscription fee for retail postpaid packages. We determined this price from the basic plans and the additional options which were on offer in the final quarter of each year. The calculated gross price of the package is the sum of the subscription fee and the prices of the added options. Meanwhile, the explanatory variables are, following the hedonic approach, the essential components of the technical, commercial and usage characteristics of the service.

Selecting the appropriate and relevant product/service characteristics for a hedonic model always requires knowledge of the product. The fact that we had control over the entire process, from data collection to coding the service characteristics, helped significantly in selecting the relevant variables.

Some basic service characteristics are related to each other, and we therefore combined them into new variables. This occurred, for example, with voice and SMS characteristics, where we created various composite variables to test out in the model.⁹ For variables with few values, we created category variables beside the continuous versions to test the robustness of the estimates to alternative functional forms.

For data allowance, we used, beside the level, also the square of the variable to address the non-linearity we saw in the data. This reduced the problem of heteroscedasticity and improved the fit without substantial loss of model generality. A separate variable measures the data allowance for EU roaming. While we expected it to be strongly connected to the domestic data allowance, it proved to be a relevant differentiator in the operator's prices.¹⁰ In this case, however, there was no need to use its square.

Some characteristics, such as the unlimited data allowance, the EU data roaming allowance and the unlimited EU data roaming allowance did not exist at the beginning of the period – for these, we only have observations for later years.

⁹ Our final variable was the aggregate number of minutes and SMS messages (including both on- and off-net allowances), but we also tested aggregating only minutes and only SMS messages, as well as aggregating only on-net and off-net allowances.

¹⁰ The EU "Roam like at home" regulation allows mobile providers to draw the included roaming data limits significantly lower in packages with large and unlimited domestic data allowance.

6.2 Modelling time frame

For the time dummy hedonic regression method, it is well established in the literature that it is best to perform the estimation for adjacent time periods as opposed to estimating on the pooled database, because there is a high likelihood that the influence of individual characteristics changes significantly over a longer period (See for example Triplett 2004, 50 or de Haan and Diewert 2013). If the content or the relative importance of the product characteristics change significantly, the estimated coefficient will be much less reliable. Our database spans six years, which is a long time in a rapidly changing mobile market. We therefore calculated our main model estimates on pairs of adjacent years, which was possible as we had a large enough number of observations for each year. We also estimated the pooled model as a robustness check, however.

6.3 Functional form

Both the linear (abbreviated as lin-lin) and the log-linear (abbreviated as log-lin) specifications seemed suitable for the functional specification of the model.

We used Box-Cox to test what transformation of the dependent variable would be optimal to bring the distribution of the dependent variable closer to the normal distribution and to make the model errors more homoscedastic. According to the test, for models closer to the beginning of the period, the value of λ was generally close to 0, suggesting the logarithmic transformation for the dependent variable. However, with later year pairs, the value of λ was closer to 1, indicating rather that no transformation from the level was needed. As the Box-Cox test did not give a clear indication for all the years, we estimated both types of models. This is useful not only because we can present the price change results both in levels and percentages, but also as a robustness check. We present both specifications below. The time dummy coefficient measures the estimated price change in both models.

For the lin-lin specification, the regression equation is

$$p_i^t = \alpha + \sum_k \beta_k * z_{i,k}^t + \delta^t * d^t + \varepsilon_i^t , \qquad (1a)$$

where

 p_i^t is the price of package combination *i* in period *t* (*t* = 0, ... *T*),

 $z_{i,k}^{t}$ is the *k*-th characteristics of package combination *i* in period t (k = 1, ..., K)

a is the constant

 β_k is the coefficient of the *k*-th characteristic (implicit price)

 d^t is the time dummy for year t

 δ^t is the coefficient of the time dummy for year t

 ε_i^t is the random error of package combination *i* in period *t*.

Equation (1b) below shows the log-lin specification, which differs from (1a) only in that the dependent variable is the logarithm of the price. However, this implies that the effects of the

independent variables are linear and additive in log and the estimates must be interpreted accordingly.

$$ln(p_i^t) = \alpha + \sum_k \beta_k * z_{i,k}^t + \delta^t * d^t + \varepsilon_i^t$$
(1b)

6.3 Weights

An important question in hedonic modelling is whether to use weights in the estimation. For example, if we knew the number of users for each package combination available on the market, we could obviously get more reliable estimates. In that case, using frequency weights (WLS) the time dummy would be a weighted index. While we do not have data on the consumption of the combinations, however, it is very improbable that they are uniformly distributed: consumers most certainly buy some package combinations in larger numbers than others. The market shares of the operators are also different and additionally, there is high variability in the number of combined packages by operator per year. So, despite the lack of "perfect" consumption data, it seems very reasonable to make some assumptions and apply some restrictions in the form of weights assigned to the package combinations.

We use the following combination of weights in our analysis:

- Market shares of the operators. We have aggregate information on operator market shares, which we use to balance out the relative weights of the operators' plans. Using market share weights, we can avoid certain operators' packages influencing results more simply because their packages are designed in a way where more possible combinations are possible, or because they have more basic plans.
- Proportion of large screen and small screen customers. There are estimates available on the average proportion of these two types of customers on the market as a whole.¹¹
- Consumption of package options. We assume that only a small proportion (10%) of users subscribe to additional options on top of their basic plan. While the 10% itself is a pure assumption, it seems reasonable. It's important to remember that the number of combinations we created by meaningfully combining basic plans with the supplementary options is much higher than the number of basic plans, but basic plans form the backbone of consumers' choice. We therefore assigned the same relative weight to each group of offers containing the same basic plan in each year, no matter how many combinations could be derived by attaching options to them, and then applied the 10% assumption. Information on ARPU seems to support this conjecture.

¹¹ We calculated the weights by using the data published by the NMHH in its regular mobile market reports, and used 2020 numbers as a substitute for the missing numbers of 2021. See the report at <u>https://nmhh.hu/dokumentum/220055/NMHH mobilpiaci jelentes 2017Q1 2020Q4.pdf</u>, and its data annex: <u>https://nmhh.hu/cikk/220115/A mobilpiaci jelentes adattablai 2020 II felev</u>.

We applied all three weightings combined in the baseline model, but for robustness also checked results without applying the large screen/small screen weighting and the 90%:10% package option weighting.

6.4 Heteroscedasticity

One key assumption in OLS is that the conditional variance of the error terms is constant, i.e. homoscedastic. With heteroscedasticity the coefficient estimates are unbiased but the t and F tests are not valid and the inference based on them will not be reliable. For handling heteroscedasticity, it helps to have a good hypothesis for the distribution of the error variance. If we know that there are connections within groups of observations, for example, we can use the estimation of the cluster-robust covariance matrix. Since we knew the tariff plans of the operator in each year are connected, we used standard errors clustered by operator and year. As a consequence, the standard errors are expected to be larger, but the inference is more reliable.

6.5 Multicollinearity

With hedonic regression models, we can easily encounter multicollinearity due to the strong correlation within certain groups of variables, causing the standard errors to be significantly larger, but not causing bias in the estimated coefficients. Fortunately, this problem does not cause bias in the estimated coefficients of other variables, although it could inflate their standard errors. Since the variables representing the relevant service characteristics in the model may be highly correlated, it is not surprising that multicollinearity occurs when they appear in the model together. Multicollinearity can be measured by the Variance Inflation Factor (VIF). The VIF value of a regression variable is the ratio of the overall model variance to the variance of a model that includes only that independent variable.¹²

Multicollinearity could be handled by eliminating one of the correlating variables, but is not suggested to leave some relevant characteristic out of the model. Another, methodologically better option is to aggregate or combine the related variables into a composite variable.

In the model specification phase, we tested for variable multicollinearity. The VIF values indicated that there should not be separate variables for the distinct voice and SMS features. On-net and off-net voice and SMS allowances included in the plan were highly correlated. To avoid any loss of information, we opted to use composite variables for voice and SMS-related characteristics.

¹² The minimum VIF value is 1. There is no strict threshold value for multicollinearity, but according to the convention, VIF below 4 is fine, but a value higher than 10 signals serious multicollinearity.

7. Results

Based on the considerations outlined in the previous chapters, and after extensive tests, we settled on the baseline models which we believe are best suited to answer our original questions. We present and interpret both a linear and a loglinear model below, then attempt to separate and quantify the effect of the outside shock, the governments' decision to decrease the tax on internet services.

7.1 The linear model

We begin with the linear model, which the Box-Cox showed to be preferred for later yearpairs. The linear model shows results in Hungarian forints (HUF) – while these can be transformed into EUR, it is important to note that the exchange rate changed significantly over the period.¹³ From the point of view of local consumers, the HUF results are more informative. We will, however, later calculate a percentage change using sample averages.

Table 2 shows the results of our baseline linear model, which uses cluster-robust standard errors, clustered by operators. The columns are labelled according to the pairs of years they refer to; thus, the column labelled 2020-21, for example, shows results based on comparing the data for 2020 and 2021.

¹³ The yearly average HUF/EUR exchange rate was 309.9 in 2015, and 351.2 in 2021, according to the Central Bank of Hungary.

	15-16	16-17	17-18	18-19	19-20	20-21
constant	2190.4 ***	3987.0 ***	2837.3 ***	2604.6 ***	3004.9 ***	2348.2 *
	(489.6)	(275.0)	(240.4)	(428.1)	(717.2)	(1057.3)
loyalty	-101.5 ***	-86.1 ***	-32.4 *	-99.0 ***	-115.5 ***	-77.3 ***
	(20.9)	(21.2)	(13.1)	(9.2)	(11.1)	(20.0)
e-discount	-205.3	-401.5 *	-623.6 ***	-490.3 ***	-400.5 **	-414.8 ***
	(333.9)	(180.1)	(101.0)	(141.1)	(140.0)	(118.4)
total minute & SMS	24.3 ***	13.9 ***	10.1 ***	15.2 ***	18.2 **	13.1 *
	(1.4)	(2.2)	(0.8)	(3.2)	(5.9)	(6.0)
unlimited minute & SMS, on-net	2582.1 *	2667.5 ***	1954.8 ***	1695.8 ***	1523.3 ***	1922.8 ***
	(1212.1)	(349.2)	(123.7)	(84.9)	(382.4)	(253.0)
unlimited minute & SMS	14373.7 ***	10973.8 ***	7204.1 ***	6892.8 ***	7187.7 ***	6605.1 ***
	(1936.5)	(1295.6)	(272.4)	(701.9)	(839.1)	(740.5)
data allowance (GB)	517.1 ***	462.8 **	248.1 ***	120.9 *	72.7 ***	69.8
	(141.5)	(179.4)	(42.8)	(54.4)	(22.0)	(40.0)
data allowance, squared	-4.4 **	-3.9 *	-1.9 ***	-0.6	-0.3 *	-0.3
	(1.4)	(1.8)	(0.5)	(0.4)	(0.1)	(0.3)
unlimited data HU		9064.5 ***	6959.3 ***	6509.4 ***	6839.2 ***	6241.6 ***
		(1448.9)	(473.6)	(674.9)	(499.0)	(961.1)
unlimited data HU & EU			8331.5 ***	10287.0 ***	7654.9 ***	6960.1 ***
			(173.6)	(104.9)	(78.4)	(263.9)
EU data allowance (GB)	-96.8	65.2	229.6 ***	226.1 ***	112.3 **	118.2
	(211.6)	(111.4)	(43.3)	(23.0)	(37.9)	(63.1)
large screen	-1856.9	-2247.2	-1442.5 *	-1247.7	99.4	1149.2
	(1649.2)	(1910.5)	(729.8)	(886.2)	(677.5)	(654.6)
video zero rating	-1026.4	-268.5	1658.0	3294.1 **	3913.7 ***	7495.0 ***
	(2045.3)	(1834.4)	(2563.8)	(1149.2)	(1026.4)	(723.4)
number of other zero-rated services	1964.9 *	921.3	742.2 ***	676.4 ***	288.5 *	338.1 *
	(827.5)	(608.1)	(164.0)	(198.0)	(129.8)	(144.5)
2016	109.7					
	(293.3)					
2017		-2346.7 ***				
		(463.2)				
2018			-916.2 **			
			(309.9)			
2019				-745.2 **		
				(262.4)		
2020					-733.8 *	
					(353.1)	
2021						415.4
						(266.0)
Ν	10321	7793	4461	3074	2250	2195
R2	0.80	0.74	0.78	0.91	0.89	0.90
Adj R2	0.80	0.74	0.78	0.91	0.89	0.90
AIC	216877	164154	89827	60317	44926	42945
E statistic	3/03	1735	11//	2100	1207	1301

Table 2. The linear model

*** p < 0.001; ** p < 0.01; * p < 0.05.

The parameter estimates for each variable show the implicit price, in Hungarian forints, of the given package attribute. For binary variables, the estimate shows how much more a package containing such an attribute costs (keeping all other relevant characteristics fixed) than a package without it. In the 2020-21 model, for example, the estimate on *unlimited data allowance* shows that packages with unlimited domestic data cost HUF 6242 more on average than packages without it.

For continuous variables, the estimate shows the effect of a unit increase on price (again, keeping all other relevant characteristics fixed). For example, in the 2020-21 model, the price increases by HUF 13 on average if the package includes an extra minute or SMS message.

Our main question, the hedonic price change is indicated in bold in the table. For each pair of years, the year dummy shows the change in average prices from the previous year, partialling out all the relevant service characteristics; that is, the quality-adjusted change in

price. The first year in each pair of years forms the base to which the second year is compared. Thus, for example, in the 2020-21 model we can see that the quality-adjusted price change is HUF 415, while in the 2019-20 model it is negative HUF 734. We will later cumulate these year-on-year changes to show the quality-adjusted price change for the entire 2015-2021 period.

For now, let's look at the models overall, and at the parameter estimates on some package characteristics specifically. First, it's apparent that most, but not all parameter estimates are significant at the 5% level. The models' fit is satisfactory, with R² values between 0.74 and 0.91. Estimates on characteristics are typically have the expected sign and plausible values.

For data allowance, the price of an extra 1GB of data has decreased significantly from 2015 to 2021. The negative sign of the squared term shows that this price is smaller for larger amounts of data. Unlimited domestic data first appears in 2017, first at a high price of HUF 9065, then stabilising around HUF 6500-7000. Unlimited domestic and EU data allowances are even higher priced.

In contrast to the data allowance variables, there is less movement in the area of minutes and SMS messaging. Minutes and SMS messages included are priced between HUF 10 and 24, with no clear trend over time. The implicit price of unlimited minutes and SMS messages is, however, always positive and decreasing, and much larger for off-net and on-net, rather than solely on-net cases.

Unlimited thematic content data allowance (i.e. zero rating) is highly priced when it refers to data-intensive videos, although this feature is not significant for most of the period – partly because the packages containing such a characteristic have low weight. Other thematic content has become gradually cheaper with time.

The large screen variable is typically not significant, its effect being presumably picked up by other variables. Loyalty discounts have a clear price-decreasing effect, calculated here by month, which fluctuates somewhat year to year, as does the e-discount.

Overall, with its good fit and with variable signs and values being consistent with economic expectations, we believe the model captures the relationship between price and the relevant service characteristics well. The main variable, the hedonic price change is negative between 2017 and 2020, and statistically significant over the same period. Before moving on to mapping and interpreting the hedonic price changes and calculating the cumulative change, we also present the log-linear model.

7.2 The log-linear model

The log-linear models' fit is slightly weaker than that of the linear model, but is easier to interpret in an international context. It also resulted in similar signs and significance levels for the characteristics and the hedonic time variables. Table 3 shows the results.

Table 3.	The l	log-l	linear	mode	2
----------	-------	-------	--------	------	---

	15-16	16-17	17-18	18-19	19-20	20-21
constant	7.758 ***	8.117 ***	8.089 ***	8.146 ***	8.183 ***	8.116 ***
	(0.176)	(0.071)	(0.104)	(0.016)	(0.077)	(0.167)
loyalty	-0.010 ***	-0.008 *	-0.004	-0.011 ***	-0.011 ***	-0.005
	(0.002)	(0.003)	(0.003)	(0.001)	(0.002)	(0.005)
e-discount	-0.058 *	-0.073 ***	-0.090 ***	-0.070 ***	-0.060 ***	-0.059 ***
	(0.027)	(0.019)	(0.026)	(0.019)	(0.014)	(0.018)
total minute & SMS	0.005 ***	0.003 ***	0.002 ***	0.002 ***	0.002 **	0.001 *
	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
unlimited minute & SMS, on-net	0.367 ***	0.483 ***	0.378 ***	0.353 ***	0.345 ***	0.372 ***
	(0.099)	(0.028)	(0.045)	(0.040)	(0.042)	(0.069)
unlimited minute & SMS	1.885 ***	1.422 ***	1.030 ***	0.902 ***	0.912 ***	0.829 ***
	(0.200)	(0.118)	(0.060)	(0.058)	(0.056)	(0.029)
data allowance (GB)	0.052 ***	0.045 **	0.032 ***	0.019 *	0.012 *	0.008
	(0.013)	(0.015)	(0.004)	(0.009)	(0.005)	(0.008)
data allowance, squared	-0.000 ***	-0.000 *	-0.000 ***	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
unlimited data HU		1.072 ***	0.825 ***	0.542 ***	0.636 ***	0.614 **
		(0.059)	(0.021)	(0.135)	(0.096)	(0.200)
unlimited data HU & EU			0.765 ***	0.975 ***	0.723 ***	0.715 ***
			(0.055)	(0.025)	(0.020)	(0.103)
EU data allowance (GB)	-0.018	0.009 *	0.028 ***	0.031 ***	0.016 ***	0.020
	(0.019)	(0.004)	(0.000)	(0.007)	(0.005)	(0.010)
large screen	0.295	0.073	-0.063	-0.195	-0.049	0.171
	(0.176)	(0.205)	(0.132)	(0.161)	(0.168)	(0.091)
video zero rating	-0.118	-0.078	0.135	0.334 **	0.432 ***	0.762 ***
	(0.183)	(0.181)	(0.228)	(0.103)	(0.095)	(0.053)
number of other zero-rated services	0.239 **	0.146	0.110 **	0.078 ***	0.015	0.038
	(0.091)	(0.075)	(0.041)	(0.023)	(0.012)	(0.037)
2016	0.029					
	(0.029)					
2017		-0.224 **				
		(0.069)				
2018			-0.086			
			(0.052)			
2019				-0.129 *		
				(0.058)		
2020					-0.056	
					(0.051)	
2021						0.050
						(0.042)
Ν	10321	7793	4461	3074	2250	2195
R2	0.87	0.81	0.81	0.89	0.85	0.82
Adj R2	0.87	0.81	0.81	0.89	0.85	0.82
AIC	24011	20310	9250	5307	4906	4678
E statistic	5000	2570	1306	1702	010	720

*** p < 0.001; ** p < 0.01; * p < 0.05.

Estimates in the loglinear model can be approximately interpreted as percentages for small changes. For example, for the total number of minutes and SMS, a result of 0.005 in the 2015-16 model indicates an approximately 0.5% increase in price if the number increases by one unit. For larger changes, however, this approximation is imperfect, giving the lower estimate of the effect. Exact results of a unit change can be calculated by using the parameter value as an exponent of *e*. For the correct dummy interpretation when the dependent variable is in log form, a correction is needed. ¹⁴ For example, including unlimited domestic data in the 2020-21 model increases price by $e^{0.634}$ -1 \approx 0.885, that is, 88.5%.¹⁵ This also implies that the hedonic price changes can also be interpreted as percentages (following the correct transformation), and the year-on-year results form a chain index.

¹⁵ 0.614 + 0.2²/2 = 0.634

 $^{^{14}}$ In fact, for dummy variables we also apply the Kennedy correction (see Kennedy 1981), using x+Var(x)/2 instead of x in the exponent.

The estimates on the characteristics are similar to the linear case in sign and interpretation, so we do not discuss them in detail here. It is worth mentioning that the prices of included minutes and text messages, as well as data, all decreased overall over the period.

Overall, the log-linear specification also provides good fit and variable signs and values consistent with economic expectations, capturing the relationship between price and the relevant service characteristics well.

7.3 The cumulative change in price for the entire 2015-2021 period

The hedonic time dummies in the models above provide the year-on-year quality-adjusted prices of mobile packages. The following Figures 4 and 5 show the results on the cumulative changes in these prices for the whole period. The graphs also show 95% bootstrap confidence intervals for the changes.



Figure 4. Cumulative hedonic price changes (HUF)

Figure 5. Cumulative hedonic price change (%)



For the whole market, we see that the price, both in terms of Hungarian forints and percentages, decreased markedly after a small increase in 2016. In the final year, however, quality-adjusted prices once again increased slightly. The figures always show the changes compared to the base year, 2015.

Overall, by 2021, the total decrease in quality-adjusted price was HUF 4217. This translates to 33.3% based on the log-linear model. This indicates an average yearly decrease of 6.5% over the 2015-2021 period.

It's important to note that the decrease in price may be somewhat overstated in terms of residential mobile postpaid subscriptions overall, since our database contains a smaller sample, that of packages sold in each given year. However, many consumers use older packages which are no longer available to new customers, and these may be more expensive.

While we do not see such dramatic price decreases in the actual prices, it is apparent how much higher the quality of similarly prices packages has become over the years, especially regarding data allowances. The hedonic method allows us to see this trade-off in price and quality, essentially showing the decrease in the price of a "unit value" of the service.

7.4 The effect of the changes in value-added tax

In addition to the evident technological and competition-induced changes in quality and price, a policy change also occurred during the observed time interval. As discussed above, the Hungarian government decreased the VAT on the internet (but not the voice and messaging) services, with the goal of stimulating an increase in internet penetration and usage. Therefore, besides estimating the overall quality-adjusted price change it is worth separating the change that stems from the tax change from the effects of the quality change and competition-induced price changes.

Specifically, the 27% VAT rate was first reduced to 18% in 2017 and further to 5% in 2018 for internet services, while the VAT on voice and text messaging (SMS) services remained at its previous 27% level.

To separate the effects of this change exactly from the effects of competition and changes in guality we would need a good counterfactual: we need to see how prices would have changed in the absence of the policy change. Possibilities would include comparing to similar domestic or international services that were unaffected by the policy change. Unfortunately, no comparable domestic services or data exist, while we have no international data; international comparison, in any case, carries its own additional challenges, as the demand/consumption patterns, the competitive and technological environment would also differ. As a second-best option, we create a counterfactual ourselves: we calculate what package prices would have been in 2017-2021 if the 27% VAT still applied to all elements. This counterfactual is imperfect in that it assumes that operators would have priced in the same manner in the absence of the policy change; economic reasoning implies that this is not the case: the VAT decrease was most likely internalised in the pricing process, in order to achieve optimal results. However, this adjustment will probably only have happened in the medium run: when the change occurred, it was designed to be passed on, and government agencies paid special attention to any recalibration of net prices. Overall, this method gives us an upper bound for the "VAT effect" and a lower bound for the change in quality-adjusted prices excluding the VAT effect.

The following graphs show the cumulative changes in HUF as well as in percentage form, based on our two models. The difference between the two is the quality-adjusted price effect once the VAT effect has been excluded.



Figure 6. Cumulative change: the total and the VAT effect (HUF)

Figure 7. Cumulative change: the total and the VAT effect (%)



The graphs show clearly that even this upper bound of the VAT change effect is quite low in comparison to the total effect we measured previously. That is, the hedonic price change is not primarily driven by the policy changes implemented in 2017 and 2018. At the same time, it is also clear that the policy change did have some effect: somewhere around 5% of price decreases can be attributed to it.

7.5 Robustness

We have made a number of decisions and a few assumptions while conducting this analysis, to make the models as realistic as possible. It is important to check whether our results are sensitive to these assumptions, whether the hedonic price changes we identified are robust to alternative model specifications and weighting.

Regarding weighting, we test how the results adjust when

- we do not correct for the ratio of large screen users to small screen users, or
- we do not assume that only 10% of consumers use combined packages.

While it may seem like we are relaxing an assumption in the second case, it is in fact equivalent to assuming that all package combinations are equally popular (within each operator's portfolio), arguably a much less realistic – and therefore stronger – assumption. We do weight the packages in each case according to operator market shares, and in the second case also apply the large screen / small screen ratio.

Regarding the sample, we also look at two possible alternatives:

• We estimate a version of the model that makes use of the basic packages only; this is another way of bypassing the issue of weighting combined packages, albeit at the cost of losing a significant part of the sample.

• We estimate a version of the model that only contains small screen packages; this is also a way of handling the screen size weighting issue, at a cost.¹⁶

And finally, we also use a different modelling approach for our final robustness check:

• We estimate only one, pooled model for the entire 2015-2021 period, containing the hedonic time dummies for each year.

Table 4 shows the cumulative results for each of these five cases, that is, the hedonic price difference for 2015-2021. All five models were estimated both using a linear and a log-linear approach. The table shows the total change, including the VAT change effects.

Specification	(1)	(2)	(3)	(4)	(5)	(6)
	Base model	Without large screen weight correction	Equal weights for all combinations	Only basic plans	Only small screen plans	Pooled model
Lin-lin						
change HUF	- 4 217	- 4097	- 5 170	- 5974	- 3998	- 3891
change %*	-38.6%	-38.0%	-34.8%	-43.7%	-35.8%	-34.4%
Log-lin						
change %	-33.5%	-32.2%	-33.7%	-45.1%	-29.4%	-30.7%

Table 4. Results from alternative model specifications

*The elements of the chain index were calculated at the average quality/quantity level of the characteristics

The cumulative hedonic price differential is between HUF -3891 and -5974 in the linear model, which, evaluated at the average levels of the variables, amounts to around -34.4 to -43.7%. The results vary between -29.4 and -45.1% in the log-linear model, which are generally close to the linear model's percentage changes. The pooled model (6) and the small screen sample typically give the lowest estimate for the price decrease. The largest changes can be seen in the model with only basic packages (4), due mainly to a large decrease in 2017.

Overall, we see that all the alternative models show very similar results to the baseline model. Both the HUF and the percentage point quality-adjusted changes in price are large and economically significant at over HUF 3891 and 29.4%, and show that our results are robust.

8. Conclusion

Mobile communication is a complex service sold in package offers, with many different characteristics changing fast as the technology, consumer tastes and market competition develop. To compare prices correctly over time we need to consider and adjust for the changing quality and quantity characteristics. This study estimated the quality-adjusted price change of mobile services in Hungary between 2015 and 2021.

¹⁶ We do not do the same for large screen packages, as there are too few of them.

The characteristics of the available packages changed significantly over this period, mostly with regard to the data part of the service. After the deployment of the LTE networks 4G became a ubiquitous service, providing faster download and upload speed, and lower latency. As a result of commercial developments, the price of a GB of data decreased, unlimited data offers arrived on the market in 2017 and have become much cheaper, as have data allowances for special thematic content (zero rating services). However, regulatory changes also took place during this period in Hungary, affecting the price and quality of the services. A two-step VAT reduction on data consumption (a decrease in the VAT on internet services) was introduced by the government in order to stimulate the growth of mobile broadband penetration and the use of digital services. We investigated the possible effects of this policy change in this paper. Further policy interventions came from European regulation: the "Roam like at home" and the network neutrality regulations. These also had an effect on the shaping and pricing of the mobile packages.

In this study we estimated the total quality-adjusted price change over the period using hedonic regression models. The total average change from 2015 to 2021 was -38.5% according to the linear model and -33.5% according to the log-linear one. Robustness checks with other model specifications and estimations on meaningful subsets of the data support the relevance of these results. This significant price decrease is the mixed effect of different forces which cannot be easily separated. We estimated the effect of the Hungary-specific government intervention, the internet VAT reduction. This showed that this policy resulted in a decrease in prices of around 5% on average in each affected year. This implies that most of the measured price change is the result of the quality and quantity changes in this period. This result is particularly striking if we consider that the cumulative inflation rate was 18,6% in the same period.

References

Court, A. T. (1939): Hedonic Price Indexes with Automotive Examples, in: The Dynamics of Automobile Demand, New York, NY: General Motors Corporation, 99-117.

Forenbacher, I., Perakovic, D. and Husnjak, S. (2016): Hedonic modelling to explore the relationship of cell phone plan price and quality in Croatia, Telematics and Informatics, 2016 Vol. 33 No. 4 1057 -1070

Griliches, Z. (1961): Hedonic Price Indexes for Automobiles: An Econometric of Quality Change, Griliches, National Bureau of Economic Research, URL: http://www.nber.org/books/repo61-1;

de Haan, J. and Diewert, E. (2013): Hedonic Regression Methods, Ch. 5 in OECD, Handbook on Residential Property Price Indices, Eurostat, Luxembourg

Karamti, C. and Grzybowski, L. (2010): Hedonic study on mobile telephony market in France: pricing-quality strategies, Netnomics, 2010 Vol11. No.3, 255 – 289

Kim, W. and Kim, Y. (2018): An estimation of quality-adjusted prices for mobile services in Korea, 22nd Biennial Conference of the International Telecommunications Society (ITS): "Beyond the Boundaries: Challenges for Business, Policy and Society", Seoul, Korea, 24th-27th June, 2018

Kennedy, P. E. (1981): Estimation with Correctly Interpreted Dummy Variables in Semilogarithmic Equations, American Economic Review, 71, 802

Lancaster, K. (1971): Consumer Demand: A New Approach, Columbia University Press

Nicolle, A., Grzybowski, L. and Zulehner, C. (2018): Impact of competition and regulation on prices of mobile services: Evidence from France, Economic Inquiry Vol. 56 No. 2, 1322 -1345

NMHH (2021): Mobilpiaci jelentés – 2017. l. – 2020. lV. negyedév, https://nmhh.hu/dokumentum/220055/NMHH_mobilpiaci_jelentes_2017Q1_2020Q4.pdf

NMHH (2022): Mobilpiaci jelentés – 2021. 1. félév, https://nmhh.hu/cikk/225890/Mobilpiaci_jelentes_2021_l_felev

OFCOM (2018): An econometric analysis of pricing trends in the UK, 19 October 2018, https://www.ofcom.org.uk/__data/assets/pdf_file/0027/123894/Econometric-analysis-of-pricing-trends.pdf

Ohta, M. and Griliches, Z. (1976): Automobile Prices Revisited: Extensions of the Hedonic Hypothesis, National Bureau of Economic Research, URL: http://www.nber.org/chapters/c3966

Rosen, S. (1974): Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition, Journal of Political Economy, Vol. 82, No. 1

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, 2004/9, OECD

Stone, R. (1956): Quantity and Price Indexes in National Accounts, OECD, Paris

Appendices

A1. Basic statistics

Variable	Mean	Standard deviation	Minimum	Median	Maximum
price (HUF)	12315	5437	1490	11490	43870
loyalty (month)	8.1	9.6	0	11	24
data allowance (GB)	11.1	24.1	0	3.5	250
EU data allowance (GB)	4.0	6.6	0	0.6	40
number of thematic					
options (zero rating)	0.9	0.7	0	1	4
total minute & SMS	112	82.4	0	110	500

Table A1. Numeric variables

Table A2. Dummy variables

Variable	Mean	Standard deviation
e-discount	0.46	0.50
unlimited data HU	0.008	0.087
unlimited data HU & EU	0.001	0.026
video thematic option (zero		
rating)	0.235	0.424
basic package offer	0.056	0.229

Table A3. Category variables

Variable	Category	n	Frequency
unlimited minutes & SMS	no	7551	0.415
	on-net only	6660	0.366
	all networks	3971	0.218
ΜΝΟ	Telekom	5232	0.288
	Telenor	9415	0.518
	Vodafone	3533	0.194
	Digi	2	0.0001
type	small screen	17386	0.956
	large screen	796	0.044

A2. Further regression results

	15-16	16-17	17-18	18-19	19-20	20-21
constant	2342.4 ***	4020.6 ***	2829.1 ***	2638.0 ***	2970.3 ***	2263.2 *
	(447.6)	(324.6)	(251.2)	(415.1)	(734.1)	(1098.1)
loyalty	-98.6 ***	-86.0 ***	-38.5 ***	-89.6 ***	-100.6 ***	-70.4 ***
	(21.2)	(19.2)	(7.5)	(8.1)	(7.6)	(19.9)
e-discount	-218.5	-400.5 **	-609.3 ***	-485.8 ***	-417.3 **	-448.9 ***
	(265.5)	(153.1)	(94.8)	(143.0)	(132.8)	(107.1)
total minute & SMS	22.5 ***	13.5 ***	10.2 ***	14.6 ***	17.4 **	13.5 *
	(2.6)	(2.1)	(0.8)	(3.0)	(6.0)	(6.4)
unlimited minute & SMS, on-net	2659.4 *	2707.7 ***	1953.8 ***	1777.8 ***	1668.2 ***	1926.8 ***
	(1099.4)	(247.5)	(110.4)	(57.1)	(287.4)	(255.4)
unlimited minute & SMS	14076.8 ***	10814.2 ***	7219.1 ***	6880.8 ***	7249.3 ***	6678.1 ***
	(1435.9)	(934.8)	(296.2)	(674.5)	(811.5)	(734.3)
data allowance (GB)	681.5 *	578.3	284.8 ***	133.8 *	77.1 ***	65.5
	(293.6)	(303.5)	(35.3)	(56.3)	(19.5)	(34.0)
data allowance, squared	-7.3 *	-5.6	-2.2 ***	-0.7	-0.3 **	-0.3
	(3.3)	(3.2)	(0.4)	(0.4)	(0.1)	(0.2)
unlimited data HU		9564.6 ^^^	/293.1 ^^^	6557.3 ***	6698.8 ***	6150.5 ***
		(1899.2)	(570.2)	(527.6)	(406.5)	(917.9)
unlimited data HU & EU			8338.4 ^^^	10036.7 ***	7449.1 ***	6928.1 ***
		10.0	(180.2)	(96.2)	(345.5)	(296.6)
EU data allowance (GB)	-1/4.6	-10.9	200.8 ***	214.0 ***	112.6 **	127.1
1	(276.6)	(177.2)	(53.4)	(19.7)	(36.0)	(67.1)
large screen	-1287.5	-2094.5	-1602.7 *	-890.8	512.2	1397.1 *
video	(2875.5)	(2564.4)	(646.0)	(1039.7)	(597.1)	(059.1)
video zero raling	-903.0	-197.0	1554.1	3527.4 ***	4140.4	(661.1)
	(2199.0)	(1701.0)	(2465.5)	(1125.5)	(1060.9)	(001.1)
number of other zero-rated services	1884.0	(131.Z (172.5)	(154.2	543.9 ^m	181.3	(126 1)
2016	(910.6)	(473.5)	(134.1)	(204.0)	(133.0)	(120.1)
2010	-27.1					
2017	(493.0)	2226 0 ***				
2017		-2320.9				
2018		(330.2)	005 0 *			
2016			-000.2			
2040			(355.5)	COC 0 ***		
2019				-636.0 ***		
0000				(185.6)	F04 0 *	
2020					-594.0 *	
0004					(294.8)	074.0
2021						3/1.9
	1000 1	7700	1101		0050	(303.4)
N	10321	//93	4461	3074	2250	2195
	0.81	0.75	0.79	0.90	0.89	0.90
	U.81	0.75	0.79	0.90	0.89	0.90
	216034	103/8/	89/59	60419	44949	42968
r statistic	3041	1800	11/8	1980	1277	1411

Table A4. Without large screen weight correction, linear

*** p < 0.001; ** p < 0.01; * p < 0.05.

Table A5. Without I	larae screen	weiaht correcti	on, loa-linear

	15-16	16-17	17-18	18-19	19-20	20-21
constant	7.767 ***	8.119 ***	8.086 ***	8.154 ***	8.185 ***	8.101 ***
	(0.166)	(0.082)	(0.105)	(0.006)	(0.082)	(0.177)
ioyalty	-0.010 ***	-0.008 *	-0.005 *	-0.010 ***	-0.009 ***	-0.004
	(0.001)	(0.003)	(0.002)	(0.001)	(0.002)	(0.005)
e-discount	-0.060 **	-0.072 ***	-0.087 ***	-0.070 **	-0.063 ***	-0.062 ***
	(0.020)	(0.017)	(0.024)	(0.022)	(0.018)	(0.019)
total minute & SMS	0.005 ***	0.003 ***	0.002 ***	0.002 ***	0.002 **	0.001 *
	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
unlimited minute & SMS, on-net	0.377 ***	0.490 ***	0.378 ***	0.366 ***	0.363 ***	0.371 ***
	(0.095)	(0.024)	(0.044)	(0.036)	(0.029)	(0.072)
unlimited minute & SMS	1.865 ***	1.417 ***	1.033 ***	0.900 ***	0.914 ***	0.833 ***
	(0.202)	(0.103)	(0.063)	(0.055)	(0.056)	(0.033)
data allowance (GB)	0.062 ***	0.052 [*]	0.036 ***	0.021 [*]	0.013 **	0.008
()	(0.015)	(0.021)	(0.002)	(0.009)	(0.005)	(0.007)
data allowance, squared	-0.001 **	-0.000 *	-0.000 ***	-0.000	-0.000 *	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
unlimited data HU	(0.000)	1 105 ***	0.857 ***	0 548 ***	0.625 ***	0.621 **
		(0.084)	(0.031)	(0 106)	(0.064)	(0 102)
unlimited data HIL 8 ELL		(0.004)	0.765 ***	0.100)	(0.004)	0.192)
			0.705	0.944	0.097	0.720
	0.000	0.004	(0.057)	(0.013)	(0.028)	(0.109)
EU data allowance (GB)	-0.022	0.004	0.025 ***	0.030 ^^^	0.016 **	0.020
	(0.018)	(0.007)	(0.001)	(0.006)	(0.005)	(0.011)
arge screen	0.467 **	0.189	-0.075	-0.169	-0.013	0.1/6
	(0.144)	(0.216)	(0.129)	(0.179)	(0.133)	(0.098)
video zero rating	-0.115	-0.080	0.124	0.360 ***	0.458 ***	0.769 ***
	(0.190)	(0.176)	(0.220)	(0.096)	(0.094)	(0.049)
number of other zero-rated services	0.235 *	0.139	0.110 **	0.054 *	-0.004	0.040
	(0.101)	(0.072)	(0.042)	(0.027)	(0.012)	(0.036)
2016	0.022					
	(0.041)					
2017		-0.230 **				
		(0.089)				
2018		· · · ·	-0.079			
			(0.058)			
2010			(0.000)	-0 116 *		
2019				-0.110		
2020				(0.046)	0.000	
2020					-0.038	
					(0.042)	
2021						0.044
-						(0.047)
Ν	10321	7793	4461	3074	2250	2195
R2	0.87	0.81	0.82	0.87	0.84	0.82
Adj R2	0.87	0.81	0.82	0.87	0.84	0.82
AIC	23413	20025	9148	5686	5114	4787
F-statistic	5882	2612	1453	1521	852	711

Table A6 F	- aual weiahts f	or all combi	nations linear
1 GOIC / 10. L	.guui weigines i	or an comon	nations, inital

	15-16	16-17	17-18	18-19	19-20	20-21
constant	5466.3 ***	7146.5 ***	4708.4 ***	4473.2 ***	4101.5 ***	3045.2
	(1419.8)	(927.0)	(529.0)	(528.2)	(948.0)	(15/0.1
loyalty	-110.8 ***	-/6.2 ***	-13.4	-74.0 ***	-105.2 ***	-85.0 ***
	(13.3)	(2.7)	(38.3)	(3.1)	(7.4)	(24.1
e-discount	-4.9	-432.0	-/6/.1 ^^^	-561.2 ***	-359.7 ^	-311.8
	(326.2)	(277.0)	(205.1)	(124.6)	(148.1)	(175.8)
total minute & SMS	19.2 ***	5.8 ^	9.8 ^^^	16.9 ***	19.9 ***	19.3 **
	(0.5)	(2.3)	(2.8)	(2.4)	(3.8)	(5.9)
unlimited minute & SMS, on-net	1517.8	1068.6	1165.0 ^	1445.2 ***	1484.9 ***	1928.1 ***
institution to 8 OMO	(1377.0)	(840.4)	(5/7.7)	(57.7)	(418.6)	(347.5)
unlimited minute & SMS	12686.6 ***	9134.3 ***	6817.3 ***	/089.7 ***	/518.2 ***	/131./ ***
	(2155.6)	(1414.2)	(983.2)	(685.7)	(503.5)	(556.3)
data allowance (GB)	483.7 ***	386.2 ***	262.2 ***	63.2	61.0 *	62.3
	(98.8)	(66.9)	(47.8)	(38.8)	(27.7)	(39.9)
data allowance, squared	-4.1 ***	-3.3 ***	-2.1 ***	-0.2	-0.2	-0.2
	(1.1)	(0.7)	(0.4)	(0.2)	(0.1)	(0.2)
unlimited data HU		/832.4 ***	6244.9 ***	4320.1 ***	4493.3 ***	4562.7 **
		(1441.4)	(707.0)	(1177.2)	(1257.7)	(1704.3)
unlimited data HU & EU			6924.6 ***	9063.8 ***	5627.9 ***	5763.4 ***
			(470.2)	(376.3)	(465.2)	(1043.2
EU data allowance (GB)	-173.8	-44.8	209.3 **	290.1 ***	141.5 *	149.3
	(181.0)	(96.0)	(78.4)	(40.8)	(61.5)	(84.9)
large screen	-3977.2 ***	-3812.7 *	-2432.9 *	-902.7	-78.4	1658.4
	(1200.6)	(1541.5)	(1013.3)	(742.4)	(1006.6)	(882.1)
video zero rating	5911.7	5299.9 *	5777.4 **	4544.5 ***	4217.8 ***	6139.3 ***
	(3123.1)	(2666.4)	(2068.2)	(776.8)	(718.0)	(1539.2)
number of other zero-rated services	858.6	535.8	617.7 ***	245.6	-239.3	121.6
	(757.4)	(359.8)	(38.2)	(134.0)	(207.6)	(311.1)
2016	-895.8 **					
	(321.0)					
2017		-1736.7 ***				
		(510.5)				
2018			-1097.6			
			(741.1)			
2019			,	-1896.4 **		
				(666.8)		
2020				()	65.7	
					(95.4)	
2021					()	390 3
						(342.7)
Ν	10321	7793	4461	3074	2250	2195
R2	0.76	0.71	0.78	0.80	0.79	0.83
Adj R2	0.76	0.71	0.78	0.80	0.79	0.83
AIĆ	198422	150819	82918	56708	41994	40273
F statistic	2696	1452	1154	870	604	761

Table A7. Equa	l weights for all	combinations, log-linear
	5	, ,

	15-16	16-17	17-18	18-19	19-20	20-21
constant	8.605 ***	8.775 ***	8.564 ***	8.527 ***	8.464 ***	8.250 ***
lovelty	(0.154)	(0.097)	(0.063)	(0.070)	(0.103)	(0.251)
loyally	-0.008	-0.006	-0.001	-0.006	-0.010	-0.005
e-discount	-0.006	-0.044 *	-0.074 ***	-0.052 ***	-0.034 ***	-0.028
e-discount	(0.024)	(0.021)	-0.074 (0.018)	-0.032	-0.034	(0.020
total minute & SMS	0.02+*	0.001 ***	0.001 ***	0.002 ***	0.002 ***	0.003 ***
	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)	(0.001)
unlimited minute & SMS_on-net	0 172	0 136	0 143 **	0 175 ***	0 214 ***	0 268 ***
	(0.111)	(0.086)	(0.048)	(0.010)	(0.022)	(0.063)
unlimited minute & SMS	1.072 ***	0.765 ***	0.632 ***	0.721 ***	0.812 ***	0.788 ***
	(0.110)	(0.101)	(0.080)	(0.082)	(0.053)	(0.062)
data allowance (GB)	0.045 ***	0.034 ***	0.025 ***	0.007	0.006	0.006
· ·	(0.011)	(0.005)	(0.004)	(0.005)	(0.004)	(0.005)
data allowance, squared	-0.000 **	-0.000 ***	-0.000 ***	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
unlimited data HU		0.753 ***	0.610 ***	0.344 ***	0.375 **	0.472 *
		(0.132)	(0.087)	(0.105)	(0.133)	(0.238)
unlimited data HU & EU			0.663 ***	0.790 ***	0.480 ***	0.611 ***
			(0.048)	(0.056)	(0.049)	(0.173)
EU data allowance (GB)	-0.019	-0.007	0.019 *	0.030 ***	0.016 *	0.020
	(0.016)	(0.007)	(0.008)	(0.002)	(0.006)	(0.011)
large screen	-0.395 **	-0.348 *	-0.222 *	-0.169	-0.075	0.271 *
	(0.148)	(0.153)	(0.092)	(0.134)	(0.215)	(0.136)
video zero rating	0.434	0.439 ^	0.508 ^^	0.431 ^^^	0.439 ***	0.624 ***
number of other zero rated convises	(0.239)	(0.209)	(0.177)	(0.056)	(0.065)	(0.151)
number of other zero-rated services	(0.061)	(0.072	(0.007)	(0.023	-0.050	(0.021
2016	-0.060 *	(0.033)	(0.007)	(0.010)	(0.010)	(0.058)
2010	-0.000					
2017	(0.023)	-0 133 ***				
2017		-0.100				
2018		(0.000)	-0.084			
2010			(0.052)			
2010			(0.052)	-0 192 *		
2013				(0.078)		
2020				(0.070)	0.010	
2020					(0.007)	
2021					(0.001)	0 040
						(0.053)
Ν	10321	7793	4461	3074	2250	2195
R2	0.78	0.71	0.77	0.75	0.74	0.73
Adj R2	0.78	0.71	0.77	0.75	0.74	0.73
AIC	3508	4338	266	929	1414	1339
F-statistic	3000	1492	1059	658	456	427

Table A8. Only basic plans, linear

	15-16	16-17	17-18	18-19	19-20	20-21
constant	3138.4 ***	5510.6 ***	2994.1 ***	2538.7 **	3485.5 ***	2592.6
	(420.8)	(494.2)	(149.5)	(777.4)	(684.9)	(1267.
loyalty	-143.1 ***	-145.5 ***	-44.7 ***	-108.8 ***	-139.1 ***	-113.3 *
	(24.0)	(19.5)	(6.5)	(15.7)	(17.3)	(21.0
e-discount	10.7	-75.1	-636.6 ***	-576.9 ***	-563.0 ***	-517.8 *
	(467.4)	(435.8)	(139.5)	(108.3)	(103.2)	(100.9
total minute & SMS	12.5	11.9 ***	10.0 ***	14.4 **	17.4 **	13.6
	(8.9)	(3.4)	(1.9)	(4.5)	(6.0)	(5.
unlimited minute & SMS, on-net	4163.7 *	3591.0 ***	2584.7 ***	1951.3 ***	1289.6 ***	1578.8 *
	(1666.9)	(654.8)	(150.6)	(77.8)	(245.9)	(251.
unlimited minute & SMS	13523.4 ***	11120.1 ***	6812.5 ***	7087.2 ***	6956.2 ***	6215.0 *
	(1475.7)	(1756.3)	(157.4)	(916.8)	(790.1)	(728.
data allowance (GB)	627.9 **	488.9 *	189.8 ***	132.5 *	66.6 ***	65
	(201.4)	(216.8)	(51.8)	(61.2)	(14.9)	(36.
data allowance, squared	-5.4 **	-4.1 *	-1.4 **	-0.8	-0.3 ***	-0
	(2.0)	(2.1)	(0.5)	(0.5)	(0.1)	(0.
unlimited data HU		7823.9 *	4586.4 ***	6302.4 ***	6617.3 ***	6123.2 '
		(3879.8)	(1334.8)	(1033.1)	(202.9)	(733.
unlimited data HU & EU			9088.0 ***	9371.8 ***	7805.6 ***	7428.0 *
			(13.8)	(290.3)	(139.3)	(440.
EU data allowance (GB)	-227.1	-59.1	344.7 ***	201.7 ***	118.2 ***	124.6
	(265.5)	(284.6)	(68.8)	(48.7)	(26.3)	(45.
large screen	-4045.5	-2773.8	-934.2	-1063.2	79.7	1225
-	(2812.1)	(2783.4)	(866.0)	(738.8)	(737.1)	(845.
video zero rating	-3514.6 ***	-2572.0	-915.8 ***	679.3	1403.5	
ç	(245.3)	(1419.9)	(213.8)	(662.4)	(800.9)	
number of other zero-rated services	2071.2 ***	563.2	455.1 **	664.8 **	289.1	404
	(507.7)	(1307.5)	(151.7)	(221.6)	(168.8)	(214.
2016	¥92.4	(, , , , , , , , , , , , , , , , , , ,	()	()	, ,	,
	(536.3)					
2017	()	-3669 4 ***				
		(770.0)				
2018		(770.0)	-1335 2 ***			
2010			(146.2)			
2019			(140.2)	-538 5 **		
2010				(106 7)		
2020				(190.7)	1162 5 *	
2020					-1103.0	
2021					(431.9)	000
2021						239
						(271.
N	389	395	286	228	213	23
KZ	0.80	0.78	0.95	0.95	0.92	0.9
Aaj K2	0.80	0.78	0.95	0.95	0.92	3.0
	/563	/633	4856	3882	3746	412
F statistic	127	106	369	295	166	15

Table A9. Only basic plans, log-linear

	15-16	16-17	17-18	18-19	19-20	20-21
constant	7.845 ***	8.338 ***	8.150 ***	8.099 ***	8.225 ***	8.119 ***
	(0.049)	(0.058)	(0.029)	(0.051)	(0.092)	(0.229
loyalty	-0.011 ***	-0.011 ***	-0.005 ***	-0.010 ***	-0.012 **	-0.00
	(0.002)	(0.003)	(0.001)	(0.002)	(0.004)	(0.005
e-discount	-0.026	-0.032	-0.077 ***	-0.071 ***	-0.065 ***	-0.055 *
	(0.026)	(0.036)	(0.020)	(0.017)	(0.012)	(0.020
total minute & SMS	0.004 ***	0.002 ***	0.001 ***	0.002 **	0.002 *	0.00
	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001
unlimited minute & SMS. on-net	0.601 **	0.555 ***	0.409 ***	0.392 ***	0.322 ***	0.329 **
	(0.190)	(0.058)	(0.056)	(0.064)	(0.028)	(0.073
unlimited minute & SMS	1 822 ***	1 267 ***	0 852 ***	0 922 ***	0 860 ***	0 747 **
	(0.096)	(0 132)	(0.041)	(0.060)	(0.070)	(0.067
data allowance (GB)	0.051 ***	0.045 **	0.029 ***	0.023 *	0.013 ***	0.01
	(0.013)	(0.045)	(0.025)	(0.020	(0.003)	(0.007
data allowanaa, aguarad	0.0013)	0.0013)	0.003)	0.003)	0.003)	0.00
uala allowance, squared	-0.000	-0.000	-0.000	-0.000	-0.000	-0.00
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	0.000
unlimited data HU		0.934 ***	0.640 ^^^	0.591 ^^	0.660 ***	0.688 ^
		(0.250)	(0.110)	(0.221)	(0.078)	(0.169
unlimited data HU & EU			0.923 ***	0.910 ***	0.761 ***	0.816 *'
			(0.015)	(0.027)	(0.024)	(0.134
EU data allowance (GB)	-0.021	-0.006	0.029 ***	0.024 **	0.013 ***	0.015
	(0.013)	(0.014)	(0.002)	(0.008)	(0.002)	(0.008
large screen	0.215	-0.071	-0.110	-0.193	-0.065	0.14
-	(0.173)	(0.277)	(0.157)	(0.153)	(0.147)	(0.129
video zero rating	-0.256 ***	-0.232 *	-0.083 *	0.076	0.202 *	
5	(0.063)	(0.117)	(0.039)	(0.041)	(0.078)	
number of other zero-rated services	0 168 ***	0.136	0 108 ***	0 094 ***	0.030	0.06
	(0.047)	(0,108)	(0.021)	(0.026)	(0.017)	(0.00
2016	0.038	(0.100)	(0.021)	(0.020)	(0.017)	(0.047
2010	(0.030					
0047	(0.040)	0 0 4 0 ***				
2017		-0.346 ^^^				
		(0.047)				
2018			-0.119 ***			
			(0.018)			
2019				-0.098 *		
				(0.045)		
2020				. ,	-0.099 *	
					(0.043)	
2021					(0.010)	0.02
2021						(0.02
N	200	205	000	000	040	(0.040
	389	395	286	228	213	23
	0.91	0.87	0.92	0.93	0.88	0.8
Adj K2	0.91	0.86	0.91	0.92	0.87	0.8
AIC	63	126	-178	-173	-40	2
F-statistic	319	191	215	189	103	8

*** p < 0.001; ** p < 0.01; * p < 0.05.

Table A10. Only small screen plans, linear

	15-16	16-17	17-18	18-19	19-20	20-21
constant	3076.2 ***	3681.9 ***	2820.9 ***	2393.5 ***	2555.4 ***	2171.2
	(553.8)	(669.8)	(256.7)	(402.4)	(387.4)	(978.4
loyalty	-101.7 ***	-83.7 ***	-44.8 ***	-109.7 ***	-122.9 ***	-77.5 **
	(20.5)	(12.1)	(4.2)	(5.4)	(8.6)	(21.9
e-discount	-190.0	-380.9 **	-592.2 ***	-510.2 ***	-426.4 **	-370.3 *
	(248.6)	(139.2)	(89.5)	(149.9)	(148.3)	(130.5
total minute & SMS	16.2 ***	11.7 ***	10.2 ***	16.2 ***	20.3 ***	13.8
	(3.7)	(0.7)	(0.8)	(2.8)	(5.5)	(6.0
unlimited minute & SMS, on-net	2252.5 **	2002.6 ***	1950.5 ***	1613.3 ***	1426.0 **	1972.4 **
	(848.5)	(299.3)	(90.2)	(116.4)	(455.2)	(260.7
unlimited minute & SMS	11422.0 ***	8893.3 ***	7214.9 ***	7030.4 ***	7217.5 ***	6734.3 **
	(1443.5)	(694.3)	(336.4)	(667.0)	(803.2)	(646.5
data allowance (GB)	1373.0 ***	1376.5 **	372.5 ***	314.8 ***	298.0	150.1
	(340.1)	(515.6)	(70.5)	(91.2)	(215.8)	(95.7
data allowance. squared	-30.4 ***	-35.1 *	-3.0 ***	-2.4 **	-2.3	-1.1
, I	(7.6)	(17.1)	(0.6)	(0.8)	(1.9)	(0.8
unlimited data HU	()	10446.7 ***	8157.9 ***	9457.1 ***	9887.4 ***	7261.3 **
		(1304.0)	(1234.2)	(1035.8)	(2908.1)	(1475.3
unlimited data HU & FU		()	8331 4 ***	10311 0 ***	8186 0 ***	6994 4 **
			(146.6)	(171.0)	(246.6)	(259.8
ELL data allowance (GB)	-201.6	-12/ 3	122.2	56 1	-33.0	68 -
	(202.6)	(148 1)	(115.4)	(56 5)	(166 7)	(87.2
video zoro rating	(202.0)	(140.1)	1545.9	2150.8 *	2917 7 **	7461 2 **
video zero ratilig	(1030.5)	(1783 7)	(2280.1)	(1028 7)	(1193.2)	(7401.2
number of other zero retad convises	(1939.3)	(1703.7)	(2300.1)	(1230.7)	(1103.2)	(740.9
number of other zero-rated services	(740.7)	-304.4	(127.9)	(168.2)	(205.0)	290.0
2016	(749.7)	(021.0)	(137.0)	(100.2)	(205.0)	(100.0
2010	-057.4					
0047	(537.0)	4405.4				
2017		-1425.1				
		(912.5)				
2018			-821.2			
			(436.7)			
2019				-584.6 **		
				(191.2)		
2020					-803.0	
					(461.9)	
2021						293.2
						(219.9
N	10055	7510	4275	2876	2006	1974
R2	0.84	0.81	0.80	0.92	0.90	0.9
Adj R2	0.84	0.81	0.80	0.92	0.90	0.90
AIĆ	209569	156416	86101	56190	39996	38604
F statistic	4911	2732	1286	2443	1372	1442

*** p < 0.001; ** p < 0.01; * p < 0.05.

Table A11. Only small screen plans, log-linear

	15-16	16-17	17-18	18-19	19-20	20-21
constant	7.807 ***	8.090 ***	8.080 ***	8.108 ***	8.093 ***	8.104 ***
	(0.178)	(0.108)	(0.104)	(0.019)	(0.035)	(0.154)
loyalty	-0.010 ***	-0.008 **	-0.006 ***	-0.012 ***	-0.012 ***	-0.005
	(0.002)	(0.003)	(0.002)	(0.000)	(0.001)	(0.005)
e-discount	-0.056 **	-0.073 ***	-0.085 ***	-0.073 ***	-0.066 ***	-0.054 **
	(0.021)	(0.016)	(0.022)	(0.018)	(0.011)	(0.017)
total minute & SMS	0.005 ***	0.003 ***	0.002 ***	0.002 ***	0.002 ***	0.001
	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
unlimited minute & SMS, on-net	0.348 ***	0.428 ***	0.377 ***	0.339 ***	0.328 ***	0.375 ***
	(0.078)	(0.046)	(0.041)	(0.042)	(0.053)	(0.064)
unlimited minute & SMS	1.719 ***	1.290 ***	1.035 ***	0.924 ***	0.916 ***	0.837 ***
	(0.206)	(0.101)	(0.069)	(0.052)	(0.052)	(0.017)
data allowance (GB)	0.102 ***	0.115 **	0.040 ***	0.048 ***	0.058 *	0.013
	(0.021)	(0.036)	(0.004)	(0.008)	(0.024)	(0.023)
data allowance, squared	-0.002 ***	-0.004 *	-0.000 ***	-0.000 ***	-0.000 *	-0.000
	(0.001)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)
unlimited data HU		1.097 ***	0.911 ***	0.999 ***	1.260 ***	0.672
		(0.071)	(0.074)	(0.024)	(0.314)	(0.364)
unlimited data HU & EU		. ,	0.764 ***	0.970 ***	0.820 ***	0.717 ***
			(0.059)	(0.043)	(0.047)	(0.103)
EU data allowance (GB)	-0.018	0.009 *	0.021 ***	0.004 *	-0.014	0.017
	(0.013)	(0.004)	(0.005)	(0.002)	(0.018)	(0.020)
/ideo zero rating	-0.100	-0.013	0.118 [́]	0.306 **	0.406 ***	0.760 ***
3	(0.175)	(0.179)	(0.213)	(0.116)	(0.118)	(0.055)
number of other zero-rated services	0.242 **	0.059	0.114 **	0.083 ***	0.034	0.034
	(0.091)	(0,100)	(0.042)	(0.016)	(0.024)	(0.042)
2016	-0.012	(/		()	()	
	(0.044)					
2017	(0.0.1)	-0 173				
		(0.147)				
2018		(0.147)	0.066			
2018			-0.000			
2010			(0.065)	0.004 *		
2019				-0.094		
2000				(0.038)	0.004	
2020					-0.064	
					(0.065)	
2021						0.043
						(0.037)
	10055	7510	4275	2876	2006	1974
२२	0.89	0.85	0.83	0.92	0.88	0.83
Adj R2	0.89	0.85	0.83	0.92	0.88	0.83
AIC	22484	18326	8826	4061	3976	4255
F-statistic	7357	3618	1591	2415	1116	726

 $\frac{P-\text{statistic}}{*** \text{ p} < 0.001; ** \text{ p} < 0.01; * \text{ p} < 0.05.}$

	(1)
constant	5162.8 ***
lovolt ((127.0)
oyany	-52.0
e-discount	-523 7 ***
	(106.0)
otal minute & SMS	11 2 ***
	(1.3)
unlimited minute & SMS, on-net	2361.3 ***
·	(457.0)
unlimited minute & SMS	8785.9 ***
	(729.8)
lata allowance (GB)	174.6 *
	(75.7)
lata allowance, squared	-1.0
	(0.5)
unlimited data HU	7894.7 ***
	(900.9)
Unlimited data HU & EU	(254.0)
El Lidata allowance (GB)	(204.9)
	(33.4)
arde screen	-308.7
	(804.0)
rideo zero rating	1731.0
	(2203.3)
number of other zero-rated services	677.9 ***
	(186.1)
2016	-330.3 **
	(115.8)
2017	-2419.1 ***
	(295.3)
2018	-2879.2 ***
22.42	(762.4)
2019	-3462.4 ^^
2020	(1094.6)
2020	-41/4.4 (1200.3)
2021	-3800 6 ***
2021	-3090.0 (1135.5)
N	18182
R2	0.72
Adj R2	0.72
AIĆ	383410
F statistic	2520

Table A12. Pooled model, linear

*** p < 0.001; ** p < 0.01; * p < 0.05.

	(4)
constant	(1) 8 304 ***
Constant	(0.034)
loyalty	-0.004
	(0.003)
e-discount	-0.076 ***
	(0.017)
total minute & SMS	0.002 ***
unlimited minute 8 CMC on not	(0.000)
diminited minute & SWS, on-het	(0.427
unlimited minute & SMS	1 122 ***
	(0.035)
data allowance (GB)	0.021 *
	(0.009)
data allowance, squared	-0.000
	(0.000)
unlimited data HU	0.813 ***
	(0.128)
unlimited data HU & EU	0.696 ***
	(0.078)
EU data allowance (GB)	0.014 ^^
larga agraan	(0.005)
large screen	0.099
video zero rating	0 165
Video Zero rading	(0.209)
number of other zero-rated services	0.087 ***
	(0.018)
2016	-0.046 ***
	(0.014)
2017	-0.220 ***
	(0.034)
2018	-0.254 ***
2040	(0.038)
2019	-0.357
2020	-0.408 **
2020	-0.400
2021	-0.374 ***
	(0.112)
Ν	18182
R2	0.76
Adj R2	0.76
AIC	51911
F-statistic	2991

Table A13. Pooled model, log-linear

*** p < 0.001; ** p < 0.01; * p < 0.05.