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Conference Paper

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

Provided in Cooperation with:

International Telecommunications Society (ITS)

Suggested Citation: Kim, Wook Joon; Kim, Yongkyu (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, International Telecommunications Society (ITS), Calgary

This Version is available at:
https://hdl.handle.net/10419/190346

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An Estimation of Quality-Adjusted Prices for Mobile Services in Korea

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June 15, 2018

An estimation of quality-adjusted prices for mobile services in Korea

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Abstract

The introduction of smartphones marked a transitional phase in the evolution of pricing for mobile communications service markets. Wireless operators migrated to supplying data centric tariffs which have characteristics that are different from the old, which makes it ever more difficult for conventional price indexes to reflect consumers' valuation in a timely and precise manner. However, little information has been known about the mobile service price developments embodying such technological change, although they are critical to our understanding of economic benefits from communications technologies. We consider service quality change to adjust the price of mobile service products. To the extent which prices are determined by quality change, taking into consideration tariffs' usage allowances practiced by operators is essential if we are to understand how prices change in the era of smartphones. We use hedonic regression techniques to estimate quality-adjusted price indexes for smartphone communication service products 2010-2017 in Korea. We investigate a total of 209 mobile plan observations sold by the major operators, where the focus is on tracing down the introduction of new plans as well as the variations in prices and characteristics over the periods concerned. We compute the weight of each observation by using a set of combined quantity data gathered from the Ministry of Science and ICT of Korea and KMPSS. The study reports the weighted averages of prices and characteristics, and chooses to implement the two-year adjacent non-linear regressions to construct estimated quality-adjusted price indices for mobile services. The results show a price decline of 8.1% per year over the periods, as specifying the timing and size of price movements across operators. We briefly discuss findings of the study to provide policy recommendations.

Keywords: hedonic price index, mobile service, smartphone, substitution, quantity weights, pricing, competition

1. Introduction

The mobile communication service market has experienced a rapid pace of technological change in product characteristics since smartphones were first introduced to the average phone users. Wireless operators around the world moved away from the pricing models based on legacy services such as voice and messaging, and began to offer data-centric price plans for a range of communication service packages that were practically nonexistent in the market. Thereafter wireless operators have chosen different means of enforcing usage limits on each service component at their own competitive advantages.

The advancement in mobile service markets, however, poses a fundamental problem of measurement bias in the Consumer Price Index unless the relationships between prices and quality change are adequately captured. How does the measurement bias take place? A number of scholars produced empirical findings on the substitution between fixed and wireless communication network services (Gerpott, 2010; Gerpott & Meinert, 2016; Kongaut & Bohlin, 2016; Shin & Kim, 2015; Srinuan & Bohlin, 2012). Broadband capabilities on smartphones make consumers switch away from both fixed broadband and traditional wireless services (Rennhoff & Routon, 2016). Not only traditional wireless services such as voice and messaging, but broadband access became readily available for smartphone users, such that a new set of baskets for 'mobile telephone service' virtually came into being, having presumably increased its expenditure weight in the CPI.[1] For example, the normalized expenditure weight for 'mobile telephone service' increases from 2.37% in 2000, to 3.38% in 2005 (Statistics Korea, 2018).[2] It is reasonable to believe that the relative importance for 'mobile telephone service' would increase at the expense of other information-related items in the CPI if the quantity demanded of data usage via 'mobile telephone service' goes up. The failure to account for this process of substitution between product groups or within each group gives rise to the problem of measurement bias in the CPI (Hausman, 2003; Moulton & Moses, 1997).

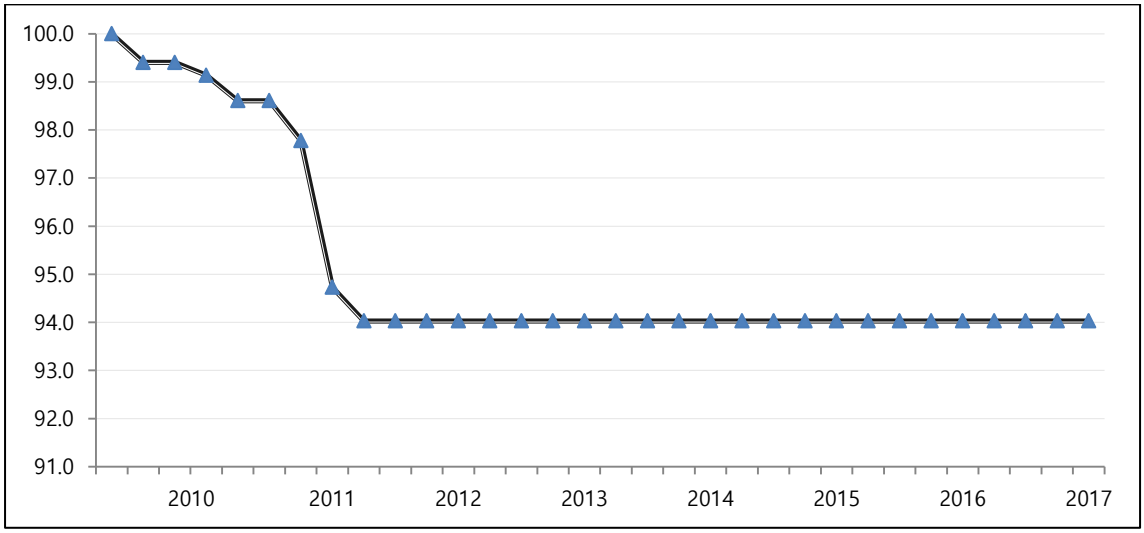
As shown in Figure 1, the CPI for mobile phone service falls from 100.0 in the 1st quarter of 2010 to 94.0 in the 1st quarter of 2012, and then levels off for the subsequent years. The CPI system implements its sampling rotation every five years, yet falls short in

[1] The term 'cellular phone service' is one of the defined items under the product group category 'Communication' in the Korea CPI.

[2] Its expenditure weight data for 2010 and 2015 is currently unavailable from Statistics Korea.

producing a timely measure of price change for new goods and outlet. The Statistics Korea's CPI system first applied a hedonic price index method to PCs in 2006, but the CPI for mobile phone service does not make quality-adjustments to prices.

Figure 1. Consumer price index for mobile phone service, Q1 2010 - Q4 2017



Source: Statistics Korea (2018)

Hedonic regression methods have found wider acceptance among national statistical agencies, and recently, attention among national statistical agencies has been drawn to measuring price trends in ICT service areas (Friedman, 2017; Corrado & Ukhaneva, 2016). In the US case, for example, in 1968, the Census Bureau was officially the first US federal agency to apply it for estimating the single family price index, addressing the heterogeneity of new houses (Musgrave, 1969). Thereafter the use of this method was dramatically growing in computers and peripheral equipment, as being able to produce an estimate of price change adjusted for changing technology and quality improvements in the industries. The US CPI started implementing hedonic methods for particular items on occasion, the categorized item "rent" in 1988, "apparel" in 1991, "computers" in 1998, etc., and they were introduced into the US statistical systems (Johnson et al., 2006). In 1999, the fraction of the price indexes that are based on hedonic methods accounted for 18 percent of the final expenditure in GDP (Landefeld & Grimm, 2000)

A large number of hedonic studies have been conducted on analyzing the ICT related products including PCs, printers, scanners, digital cameras, etc. In recent years there has been a growing number of research on the use of hedonic regression techniques for estimating the

price of ICT services such as mobile telephony, fixed broadband (Dewenter et al., 2007; Forenbacher et al., 2016; Greenstein & McDevitt, 2011; Huang et al., 2006; Karamti & Grzybowski, 2010; Koutroumpis et al., 2009; Prud'homme & Yu, 1999; Stranger & Greenstein, 2007; Varoutas et al., 2008; Wallsten & Riso, 2014; William, 2008; Yu & Prud'homme, 2010). Several studies make attempts to understand how broadband service providers behave in a manner that is consistent with price indexes (Calzada & Martinez-Santos, 2014; Karamti & Grzybowski, 2010; Stranger, 2007).

Stranger & Greenstein (2007) performs a log-linear hedonic regression using the dataset covering fixed broadband service plans 1993-1999 in the US. They investigate the pricing decisions of numerous ISPs that enter and exit the market, and suggest that quality change be considered to avoid underestimating the price declines largely driven by the introduction of new products. They conclude that the price change is substantial at the early years of broadband, indicating a cumulative decline of 49%. Greenstein & McDevitt (2011) estimates quality-adjusted price changes of fixed broadband services 2004-2009 in the US, suggesting a range of 3-10% decline over 5 years. Considering a dramatic price change in ICT products such as CPUs, laptops, printers, they see that their estimates indicate a modest decline.

Yu & Prud'homme (2010) estimates quality-adjusted price indexes for fixed broadband service plans between 1993 and 2000 in Canada. They provide a series of statistical tests to evaluate the performances of different functional forms employed for hedonic regressions, and present empirical findings about how broadband services are incorporated into the CPI. The results show that the average decrease is around 15% per year, where a drastic annual fall of around 25% per year occurs from 1993 to 1996. William (2008) compares different non-linear functional forms to provide a fixed broadband hedonic model for the CPI, finding that the estimates have downward discrepancies with the CPI.

Koutroumpis et al. (2009) constructe a hedonic price index for both residential and business European markets in 2007 – Germany, Austria, France and Iceland. They use the Box-Cox method as statistical tests for different functional forms to find the appropriate transformations of the variables concerned. The study of Koutroumpis et al. (2009) is also concerned with specifying the empirical relationships between prices and characteristics, as suggesting that download speed is the most important factor, and fixed telephony in the bundles is positively related to price. Using sliced inverse regression (SIR) and local

polynomial regression (LPR), Varoutas et al. (2008) estimate quality-adjusted price indexes for leased lines 1997-2002 in the Greek market. The estimates show a 50.3% decline in 1999 from the base year 1997, and the average annual decrease of 4.3% follows thereafter.

Little attention has been paid to analyzing mobile communication service markets along the hedonic lines we review above, in spite of its rapid pace of technological change, all exerting effects on the level of price. Karamti & Grzybowski (2010) estimates a quality-adjusted price index for mobile telephony over the period 1996-2002 in French. In analyzing how prices change in response to changes in characteristics, they find that vertical differentiation induces the price declines which are mostly limited to the periods of 1996-1998. Forenbach et al. (2016) analyze mobile service plans 2009-2013 in Croatia, illustrating the similar pricing behavior of three major providers in the market.

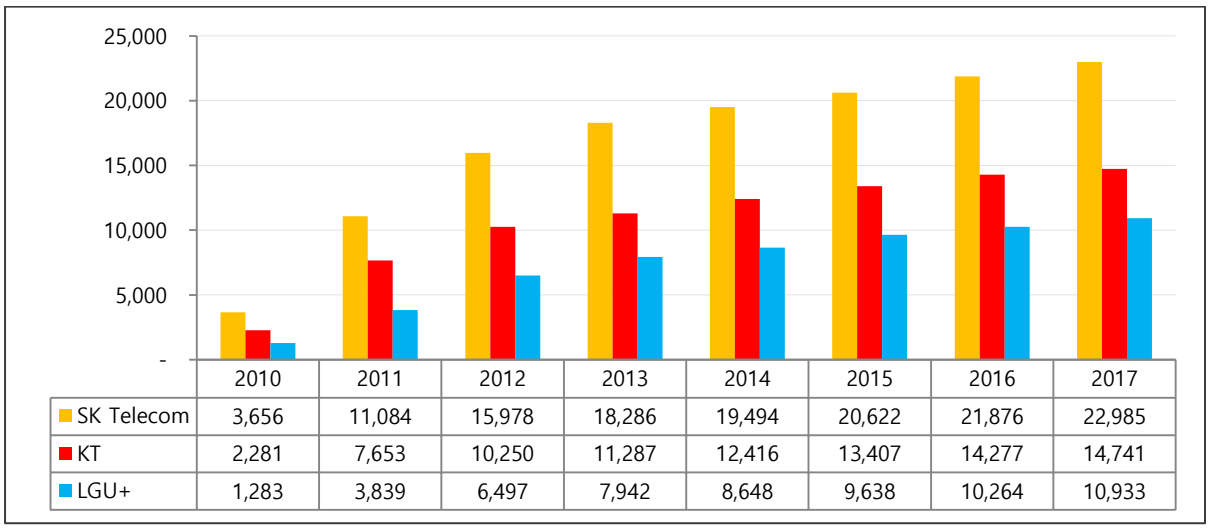
Our research contributes to the existing body of literature in several aspects. First, this paper employs hedonic regression techniques to mobile broadband service markets in the context of smartphones. Previous hedonic studies, however, have little to say about the phenomena of data-centric mobile communication markets, because they use those observations offered during the period before the introduction of smartphones (Forenbach et al., 2016; Karamti & Grzybowski, 2010). While Lyons (2016) acknowledges innovations in mobile broadband pricing, our research includes data usage variables including data, mvoip, unlimitedness, etc., as they make new products. This paper provides empirical evidence on how prices change in response to changes in data usage allowance. Second, we use publicly available information to form the weights for each observation in order to make the estimated price indexes more representative of the market.

2. The mobile telephony market in Korea

For the last decade, the mobile telephony market in Korea has experienced a steady growth in subscription and revenue. The number of mobile subscribers amounts to 62.7 million as of June 2017. The market is currently being dominated by 3 major operators: SK Telecom (43.1%), KT (25.8%), and LGU+ (19.7%), all constituting more than 88.5% of total wireless subscription in December 2017, whilst MVNOs' market share rose from 0.6% in 2010 to 11.5% in 2007 (Ministry of Science and ICT of Korea, 2018). The Herfindahl Hirschman Index (HHI) for the market has dropped since MVNOs were allowed to enter the market in 2012. However, the market is still concentrated, for the revenue based HHI is 3,417 and the subscriber based HHI, 2,953, as of 2016 (KISDI, 2017).

The number of smartphone subscribers was 22.6 million, accounting for 43.4% of total mobile subscription in 2011, and it surpassed feature-phone subscriptions in 2012, growing to make up 76.4% of all mobile connections in 2017. As shown in Figure 2, the adoption of smartphones grew exponentially 2010-2011, at an annual rate of 212.7%, adding a further 15.4 million connections. In 2017, the market for smartphone subscription is likewise made up with the major operators: SK Telecom (47.2%), KT (30.3%), and LGU+ (22.5%), each for the combined subscription of MNO and MVNOs.[3]

Figure 2. Smartphone subscriptions by firm (thousands)



	2010	2011	2012	2013	2014	2015	2016	2017
SK Telecom	3,656	11,084	15,978	18,286	19,494	20,622	21,876	22,985
KT	2,281	7,653	10,250	11,287	12,416	13,407	14,277	14,741
LGU+	1,283	3,839	6,497	7,942	8,648	9,638	10,264	10,933

Source: Ministry of Science and ICT of Korea (2018)

[3] The MVNOs' smartphone subscriptions are not separately documented in the government's published data. The figures are based on the licensed network operators partnered with MVNOs.

We explore several government and enterprise actions associated with pricing and quality change. In 2011, the operators agreed to lower the basic fee by 1,000 KRW (a little less than a US dollar), but instead to add 50 texts to existing tariff plans. The operators launched LTE service plans in July, 2011, and the LTE subscriptions have rapidly increased to 77.4% of total mobile subscribers in 2017 (Ministry of Science and ICT of Korea, 2018). A series of LTE plans have been introduced, such as LTE-A and broadband LTE in 2013, broadband LTE-A in 2014, and 3 Band LTE-A in 2015, increasing the average download speed up to 133.4 Mbps in 2017 (Ministry of Science and ICT of Korea, 2017). In 2014, the operators also took action to reduce the overall rate for data.

Nonetheless, there have been concerns about lack of competition. The market allegedly does not have much of price differentiation among products, illustrating the absence of any voluntary competitive pricing behavior by the operators. The KISDI concludes that competition is unsatisfactory, considering a difference of 18% point in market share between the leading operator and the second largest operator (KISDI, 2017).

New goods problem

The conventional fixed basket indexes would have a biased estimate of the cost of living index for mobile service prices, provided that new plan products have a chief contribution to the price change for the periods concerned. Instead of just staying with old plans, smartphone consumers shop for new service opportunity in times when two-year contracts expire or they upgrade phone devices. In Korea, the 3G pricing plans that were introduced in the early years of smartphones survived in a number of newly launched LTE pricing plans since 2011. These LTE services provide download speeds up to 30~100 Mbps, compared to 10~20 Mbps of 3G. The data allowances of the 15 LTE pricing plans introduced in 2011 averaged a little over 7GB, being twice more than in 2010, with 17.2 percentage point higher in price. The period 2010-2011 marked the most rapidly increasing slope in smartphone penetration in Korea. Thus, the failure to include the effects of new products is potentially a critical source of upward bias in the price index for mobile services markets (Benkard & Bajari, 2005; Hausman, 2003; Pakes, 2003).

Any mobile service offerings that are sold in the marketplace for only certain periods of time cause a problem of missing observations in sampling procedure. There could be a

number of reasons for this problem. Once mobile service products enter the market, almost of all tend to survive with unchanged characteristics into other years. In fact, however, some products are often offered with differing characteristics or prices in subsequent years, mostly more limits in data or voice. Noting that new mobile service products become obsolete in a few years, we base our regressions on the assumption that all the plans exit three years after being in the market. Table 1 provides information on the number of new product observations by firm from 2010 to 2017, giving a total of 209 and 744 for General and Selective plans, respectively.

Table 1. Number of new product observations by firm, 2010-2017

Year	No. of new product observations				
	General				
	SK Telecom	KT	LGU+	Total	N
2010	7	7	6	20	20
2011	7	0	8	15	35
2012	0	11	0	11	46
2013	16	26	38	80	126
2014	0	20	3	23	129
2015	18	12	27	57	171
2016	0	0	3	3	163
2017	0	0	0	0	83

3. Data

We organized a survey of mobile service plans to track down how price and technical characteristics have changed in different time periods, giving time-series observations on each individual. We were able to obtain transaction level data from sources including firms' online database, agreements, the Korea Information Society Development Institute's yearly Wireless Competition Reports, etc. The 2010-2015 data were originally gathered and analyzed by Kim (2015) and they have been updated to 2017. We collected data on download speed from the yearly Telecommunications Service Performance Reports published by the Ministry of Science and ICT of Korea: they are treated as continuous variables, but are observable only at firm level.[4] We also use data on monthly mobile phone service expenditures from the Korea Media Panel Survey Statistics (KMPSS), a national survey conducted by KISDI.[5]

The data set for this study include price and characteristics of mobile service plans offered by three major wireless operators – SK Telecom, KT, and LGU+ in Korea from 2010 to 2017. We investigate only the postpaid phone plans targeted to smartphone users, since the prepaid plans represents a small fraction of the market, accounting for no more than 6 percent for the past years.[6] We use the tired standard mobile plans whose characteristics contain data services bundled with voice and messaging, so data-only plans are not included in the sample. The postpaid plans can be classified into three types: (1) General (2) Selective (3) Juvenile/Aged. The type 'General' has been the most widely used smartphone plan type, offering a set of characteristics, whose allowances vary collectively in proportion to the level of price. The type 'Selective' offers a matrix style combination of usage quantity allowances – mainly among data, voice, and messaging, corresponding to the level of price. Consumers are allowed to choose each level of usage limits to be combined. The type 'Juvenile/Aged' refers to those targeted to specific age groups, and our dataset does not cover this type. Our analysis is focused on the type 'General' only, as it is available to any consumers and almost all consumers are currently signed up for this type.

[4] Downstream capacity is observed for each model observation in fixed broadband markets, given that advertised speeds are the primary source of product differentiation. However, since network performance is not distinguished from one contract to another in purchasing mobile service plans, it is not feasible to observe network performance on individual level.

[5] The KMPSS surveys over 6000 individuals per year containing information of media usage.

[6] The post-paid service plans account for 94.3% of total mobile subscriptions in 2017, referred to as flat rate plans being offered with usage limits on data, voice and messaging.

Weighting

A number of studies for estimation of price indexes have rallied support for the use of weights, as it is desirable to be able to use weights that make the samples representative (Aizcorbe, 2014; Diewert, 2005; Hausman, 2003). The assumption of putting equal weights on a variety of different service plans is unrealistic, and it leads to estimates substantially different from the population. In situations where a market is dominated by a small number of companies, the resulting bias seems stronger due to the size of samples. However, market share information is not always available to the public, and the cost of collecting data on market shares at product group levels is immense.

We attempt to focus on calculating the weights by utilizing publicly available sources of data. As noted earlier, we form the weights for individual plan observations by using the two main sources: the Ministry of Science and ICT of Korea's monthly reports on the firms' market shares for smartphone subscribers and the frequency distributions of mobile service expenditure reported by KMPSS. Here the quantity weights are defined by the relative share of smartphone users subscribing to each mobile service plan in a period.

Table 2. Percentage frequency of mobile phone service expenditure interval, 2010-17

Expenditure per month (KRW)	2010	2011	2012	2013	2014	2015	2016	2017	Mean
Less than 10,000	1.2	1.1	9.2	0.5	0.4	1.2	0.5	0.4	1.8
10,000-20,000	13.1	12.5	9.1	8.3	7.9	6.3	6.6	5.8	8.7
20,000-30,000	22.3	19.8	14.1	12.3	9.4	9.0	10.0	7.7	13.1
30,000-40,000	21.5	21.4	16.8	16.1	17.8	19.5	20.5	14.0	18.4
40,000-50,000	13.5	12.5	13.0	16.8	16.9	17.5	19.6	13.0	15.4
50,000-60,000	10.1	13.1	13.9	15.9	15.2	15.2	17.9	15.0	14.5
60,000-70,000	5.2	6.5	12.2	15.9	16.2	15.2	13.3	15.1	12.4
70,000-80,000	3.6	4.9	5.5	8.7	10.0	8.7	6.3	11.6	7.4
80,000-90,000	2.3	3.1	2.8	2.7	4.2	4.0	3.0	8.4	3.8
90,000-100,000	1.5	1.3	0.9	0.7	0.9	1.2	1.0	4.3	1.5
More than 100,000	5.8	3.5	2.3	2.1	1.1	2.0	1.2	4.7	2.8
Un-responded	0.1	0.2	0.2	0.0	0.0	0.1	0.1	0.1	0.1

Source: KMPSS (2017)

Table 2 tabulates the frequency distributions by expenditure intervals being

compared over the periods, based on the results of the Korea Media Panel Survey that includes the question “During the past 3 months, how much did the respondent spend on mobile phone service on average?” Notice that the distributions are skewed to the right, but its skewness slightly declines over time. The median frequency increases from the interval with 30,000-40,000 in 2010 to 50,000-60,000 in 2017, showing a steady trend toward more spending on cellular phone services. The combined percentage that falls within the range of the three highest intervals (more than 80,000) amounts to 17.4% in 2017, compared to the average 6.8% in the preceding years.

The KMPSS provides valuable information on the quantity demanded of cellular phone services for a given level of expenditure. To the extent that the price paid for a service product constitutes a considerable portion of the expenditure, the percentage frequency serves as the share of observations of each plan. It is reasonable to believe that the frequency represents the average distribution of mobile phone subscribers for the level of price of a service product in the market. We incorporate the frequency into the calculations of the quantity weights in accordance with the firms’ market shares. These weights yield approximation, however, as conditioned on the assumption that the firms have the same distribution.

Table 3. Weighted means of prices and characteristics by firm, 2010-2017

	Attributes	2010	2011	2012	2013	2014	2015	2016	2017
Weighted	PRICE(KRW)	34,834	38,086	41,236	45,007	47,199	47,188	45,445	48,219
	DATA(MB)	1,662	2,254	3,911	3,911	6,386	6,000	5,386	8,262
	VOICE(Minutes)	305	319	361	1,341	1,800	4,649	4,761	7,624
	SMS(No.)	331	365	385	4,745	5,991	7,717	7,928	7,851
	MVOIP(MB)	212	267	345	333	323	2,276	2,068	5,693
	VIDEOCALL (Minutes)	183	192	216	200	182	150	139	134
	SPEED(Megabits/s)	2	2	3	18	41	36	65	69
Un-weighted	PRICE(KRW)	43,550	46,571	47,870	51,961	54,535	55,066	54,771	56,834
	DATA(MB)	2,963	4,721	6,193	7,705	10,036	9,814	9,780	11,389
	VOICE(Minutes)	450	485	486	2,040	2,786	4,784	5,477	7,330
	SMS(No.)	520	514	537	4,568	5,545	7,033	7,339	8,108
	MVOIP(MB)	433	417	542	513	532	3,243	4,075	6,896
	VIDEOCALL (Minutes)	271	292	293	257	234	186	167	127
	SPEED(Megabits/s)	2	2	3	17	41	35	60	66

4. Model

The dependent variable PRICE (measured in KRW) is measured by the advertised retail price on a monthly basis (taxes not included). The price information has a pair of two values: one is under a two-year contract, and the other without contract. Consumers pay the full price with no contract plans, whereas they get a discount throughout the contract years. The amount of price under two-year contract are regressed on the quantities of the characteristics. The wireless carriers offer the official rates of discount of the post-paid pricing plans, and these advertised rates of discount vary with the length of contract. It is noteworthy that the actual amount of discount is never identical even for the same contract plan subscribers, but instead it varies depending on local dealers, handset models, government handset subsidy levels, etc. We do not take into considerations such variances due to data unavailability. Any refundable payment (e.g. gift certificates, cashback rebates) is not chosen on the calculation of the price.

Characteristics data include DATA (the amount of Internet data usage allowance, measured in megabytes [MB]), VOICE (the amount of voice calls out of network, including both fixed and wireless, measured in the number of minutes), SMS (the number of short messaging), MVOIP (the amount of voice calls over IP, measured in megabytes [MB]), VIDEOCALL (the number of video calls, measured in the number of minutes), and SPEED (the average cellular connection speed of both LTE and 3G, measured in megabits per second). Characteristics data also include information on whether or not each plan covers particular features. The dummy variables for characteristics include UNLIMITDATA (=1 if plan has unlimited data usage), UNLIMITVOICE (=1 if plan has unlimited voice calls), UNLIMITSMS (=1 if plan has unlimited short messaging).[7] A set of dummy variables includes time and firm.

Let P_{it} represent the price of the i^{th}mobile service plan in t^{th} year. Then X_j is denoted as the quantity of the j^{th}characteristics associated with the i^{th} model in t^{th} year. Let D_t represent the time dummy variable with a value of 1 in period t and 0 otherwise. The time dummy variable coefficients γ_t are estimates of the aggregate price change

[7] This study uses the term 'unlimited' just as is publicly advertised by operators, without regard to whether or not its usage is truly unlimited. Technically, it is termed conditional on the consumption of the services, because several restrictions are enforced in cases of various excessive uses. It is worth noting that there has not been any settled criteria by which a plan is labeled 'unlimited' to obtain the rewarding aspect of it.

between t and $t+1$ holding constant the variation in the quantities of the characteristics of mobile service plans.

$$\mathrm{P}_{it} = \beta_0 + \sum_{j=1}^{\mathrm{N}} \beta_j X_{ijt} + \sum_{t=2}^{\mathrm{T}} \gamma_t \mathrm{D}_t + \epsilon_{it}$$

We extend Diewert's (2005) weighting frameworks to our hedonic regressions where the samples in two adjacent periods are pooled. As noted early, we consider the quantity to obtain the least squares estimators for the transformed equation, and perform a set of separate regressions on the data of the different weights. Based on the specification test results, both the log-log model and the log-linear model perform better to fit the data compared with the linear model.

The time dummy hedonic index formula involves the ratio of the geometric value of prices in the two periods, divided by the quality adjustment factor. Let n represent the number of mobile service plans observed in t^{th} year, and m represent the number of plans in $t-1^{th}$ year.

$$\frac{\left[\prod_i^n (\mathrm{P}_{i,t})^{1/n} / \prod_i^m (\mathrm{P}_{i,t-1})^{1/m}\right]}{\exp\left[\sum \beta_j \left(\sum \frac{X_{i,j,t}}{n} - \sum \frac{X_{i,j,t-1}}{m}\right)\right]}$$

The study experiments with several functional forms, and finds out that the non-linear models are more suitable for fitting the data than the linear models, which is similar to that illustrated by previous hedonic studies. We set up two configurations: the log-linear model and the log-log model. Tables 4 and 5 illustrate the key regression results of these models. According to our analysis of the residuals, the log-log model is preferred because it has a higher goodness of fit and its residuals are more compatible with normality. The adjusted R-squared value in each of the models is reliable, ranging from 0.79 to 0.98. These two proposed models have a good explanatory power of the variability in the variables, as compared with the previous hedonic studies of fixed broadband access. Koutroumpis et al.'s (2009) Box-Cox transformation had R squared values around 0.74. Yu & Prud'homme (2010) generated the R squared values between 0.5 and 0.9.

5. Results

Table 5 reports the regression results of the log-log model. The DATA coefficient for 2012-2013 suggests that a 1% increase in DATA is associated with a 0.25% increase in price. Specifically, the average user in 2013 pays 2,245 KRW (≅ $2.0) for additional 1 GB in DATA. The effect of PRICE on price is slightly diminishing in subsequent years. The DATA elasticity of price for 2015-2016 is around 0.2%, meaning that the average user in 2016 pays 1,662 KRW(≅ $1.5) for additional 1GB in DATA. The estimated coefficients of both VOICE and SPEED are positive, and their price effects grow on a small scale. The SMS coefficients are also positive, but its price effect diminishes over time.

We expected the price to be higher with UNLIMITED usage factors, and thus we anticipated that their coefficients will be positive. However, they have the unexpected negative effects on price, and the estimates are often found to be not significantly different from zero at a 10% significance level. This result is counterintuitive, and it is hard to imagine how the profit maximizing price for UNLIMITED could be negative. We test whether the coefficients of the UNLIMITED variables for DATA, VOICE and SMS are jointly zero, and the results show that at least one of the UNLIMITED variables does affect the price at a 1% significance level, with the exception of 2016-2017.

Note that the time dummy coefficients are mostly negative, indicating that the quality-unadjusted prices fall. However, they turn out to be positive for 2016-2017, and the quality-adjusted prices bottom out as well. Our empirical results suggest that most of the observed characteristics be positively associated with prices, except UNLIMITED usage variables, which requires a further explanation. The effects of DATA, VOICE, and SPEED on price have been slightly lowered whilst SMS has a diminishing price effect.

Table 4. Regression results of weighted log-linear

	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017
DATA	**4.800E-06***	**5.030E-06*****	**1.030E-05*****	**5.930E-06*****	**6.940E-06*****	**7.470E-06*****	**5.460E-06*****
	(1.74)	(3.04)	(6.04)	(6.25)	(6.52)	(5.29)	(5.04)
VOICE	**-0.008****	-0.007	**1.510E-05*****	**1.550E-05*****	**8.890E-06*****	2.730E-06	1.880E-06
	(-2.17)	(-1.32)	(8.93)	(14.71)	(3.34)	(0.91)	(0.59)
SMS	**4.730E-05****	2.060E-05	-2.630E-06	-4.360E-06	**-1.360E-05*****	**-1.180E-05*****	**-2.020E-05*****
	(2.42)	(1.02)	(-0.08)	(-0.78)	(-2.91)	(-2.74)	(-3.48)
MVOIP	3.270E-06	4.870E-06	1.680E-05	**1.050E-04*****	1.480E-06	9.640E-07	1.380E-06
	(0.50)	(0.70)	(1.18)	(3.47)	(1.16)	(0.86)	(1.17)
VIDEOCALL	**0.013***	0.011	**2.360E-04*****	**3.380E-04*****	**4.010E-04*****	**4.130E-04*****	**2.420E-04*****
	(2.19)	(1.34)	(3.13)	(6.87)	(8.80)	(7.33)	(3.30)
SPEED	**0.029*****	**0.024*****	**0.010*****	**0.006*****	**0.005*****	**0.002*****	**0.001*****
	(11.02)	(12.55)	(15.35)	(19.39)	(16.89)	(7.33)	(3.65)
Unlimited DATA	**0.013****	**0.012***	**0.025*****	0.007	-3.600E-05	-0.004	0.002
	(2.11)	(1.80)	(2.68)	(0.80)	(0.00)	(-0.23)	(0.08)
Unlimited VOICE			**-0.079*****	**-0.077*****	-0.014	0.031	0.012
			(-5.11)	(-5.23)	(-0.57)	(1.12)	(0.41)
Unlimited SMS			0.047	0.070	**0.134*****	**0.158*****	**0.240*****
			(0.16)	(1.42)	(3.34)	(4.19)	(4.67)
Year	**-0.104*****	**-0.130*****	**-0.661*****	**-0.356*****	**0.062*****	**-0.161*****	**0.078****
	(-3.48)	(-3.96	(-15.27)	(-12.74)	(2.65)	(-5.57)	(2.27)
Constant	**11.66*****	**11.53*****	**11.44*****	**10.91*****	**10.74*****	**10.92*****	**11.03*****
	(245.85)	(289.94)	(265.71)	(326.50)	(289.87)	(327.76)	(274.18)
N	55	81	172	255	300	318	230
Adjusted R2	0.91	0.83	0.88	0.86	0.82	0.79	0.80

Bold*: Statistically significant at 10% level
** Significance at 5% level
*** Significance at 1% level
Parentheses: Robust t-statistics

Table 5. Regression results of weighted log-log

	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017
DATA	0.050	**0.070*** **	**0.246*** **	**0.206*** **	**0.212*** **	**0.197*** **	**0.191*** **
	(0.88)	(4.48)	(13.79)	(11.87)	(22.38)	(23.19)	(20.96)
VOICE	-2.004	**-13.976** **	**0.021*** **	**0.028*** **	**0.038*** **	**0.046*** **	**0.059*** **
	(-0.23)	(-2.40)	(2.66)	(4.26)	(4.91)	(5.09)	(3.63)
SMS	**0.121*** **	**0.118** **	**0.138*** **	**0.093*** **	**0.062*** **	**0.032** **	0.011
	(2.83)	(2.44)	(6.98)	(5.57)	(4.28)	(1.99)	(0.57)
MVOIP	**-0.021***	0.001	0.008	**0.047*** **	**0.017*** **	**0.011*** **	**0.010** **
	(-2.05)	(0.12)	(0.66)	(3.81)	(3.76)	(3.22)	(2.24)
VIDEOCALL	2.352	**14.312** **	0.029	**0.028** **	**0.033*** **	**0.025*** **	0.013
	(0.27)	(2.46)	(1.65)	(2.42)	(3.35)	(2.83)	(1.24)
SPEED	0.033	0.024	**0.051*** **	**0.125*** **	**0.166*** **	**0.224*** **	**0.247*** **
	(0.49)	(1.64)	(2.82)	(5.27)	(7.26)	(8.80)	(10.10)
Unlimited DATA	**-0.016*** **	**-0.017*** **	**0.017*** **	0.000	**-0.022*** **	**-0.017*** **	0.001
	(-3.84)	(-5.08)	(3.38)	(0.03)	(-3.79)	(-3.40)	(0.10)
Unlimited VOICE			0.007	0.008	-0.000	-0.033	-0.080
			(0.25)	(0.42)	(0.00)	(-0.98)	(-1.24)
Unlimited SMS			**-0.354*** **	**-0.237*** **	**-0.142*** **	-0.052	0.010
			(-5.31)	(-4.49)	(-3.10)	(-0.98)	(0.15)
Year	-0.028	-0.023	**-0.134*** **	**-0.119*** **	0.005	**-0.126*** **	**0.048*** **
	(-1.03)	(-1.67)	(-2.97)	(-5.05)	(0.54)	(-7.63)	(3.54)
Constant	**12.29** **	**18.23*** **	**10.60*** **	**10.36*** **	**10.07*** **	**9.89*** **	**9.67*** **
	(2.76)	(6.23)	(177.16)	(115.97)	(101.58)	(93.43)	(85.70)
N	29	57	154	244	297	316	228
Adjusted R2	0.98	0.97	0.97	0.97	0.96	0.96	0.97

Bold*: Statistically significant at 10% level
** Significance at 5% level
*** Significance at 1% level
Parentheses: Robust t-statistics

As shown in Table 6, the chained Laspeyres and Paasche indexes are constructed using weights derived from quantity, and their average annual changes are 0.2% and zero over the periods, respectively. Note that they are not based on hedonic regressions in this study, but calculated from using the weighted average of price changes. We find our standard price indexes similar to the CPI mobile phone service price index, as practiced by the KOSTAT.

$$\mathrm{I}^{L}_{t-1,t} = \frac{\sum_{i=1}^{n} P_{n,t} Q_{n,t-1}}{\sum_{i=1}^{n} P_{n,t-1} Q_{n,t-1}}$$

$$\mathrm{I}^{P}_{t-1,t} = \frac{\sum_{i=1}^{n} P_{n,t} Q_{n,t}}{\sum_{i=1}^{n} P_{n,t-1} Q_{n,t}}$$

Table 7 shows the quantity-weighted hedonic price indexes calculated from the log-log function coefficients for the adjacent periods. The estimated average rate of price change is -8.1% per year. The price indexes for the operators take the values around their average throughout the periods, though they move at different levels. However, the differences appear narrow. Figure 3 displays the cumulative flow of price change. The price began to drop sharply from 2012, a year after smartphone adoption dramatically took off. Then the price decline stabilizes in 2014. Figure 4 displays the cumulative flow of quality change. The quality index varies inversely with the level of price. The quality indexes for the operators move together at different levels, but the gaps are wider than those in price change.

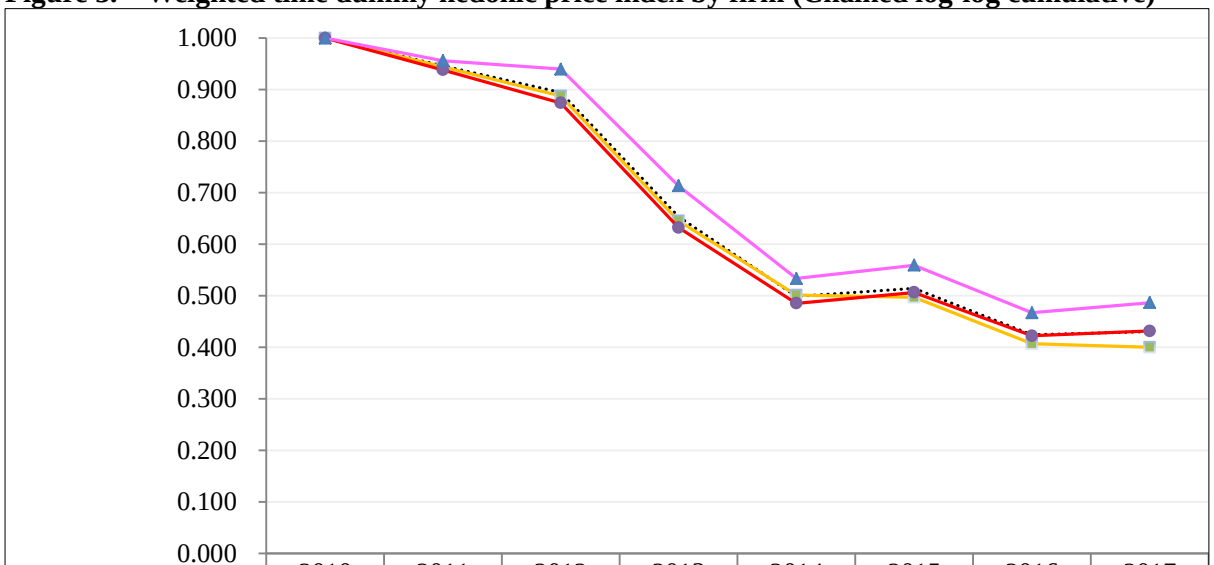
Table 6. Standard Price Indices

	2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017
Laspeyres	1.000	0.986 (-1.4%)	1.105 (12.1%)	1.000 (-9.5%)	1.000 (0.0%)	0.998 (-0.2%)	0.971 (-2.7%)	1.000 (3.0%)
Passche	1.000	0.990 (-1.0%)	0.996 (0.6%)	1.000 (0.4%)	1.000 (0.0%)	1.003 (0.3%)	1.000 (-0.3%)	1.000 (0.0%)
Fisher	1.000	0.988 (-1.2%)	1.049 (6.2%)	1.000 (-4.7%)	1.000 (0.0%)	1.000 (0.0%)	0.985 (-1.5%)	1.000 (1.5%)

Table 7. Weighted hedonic indices by firm (log-log time dummy method)

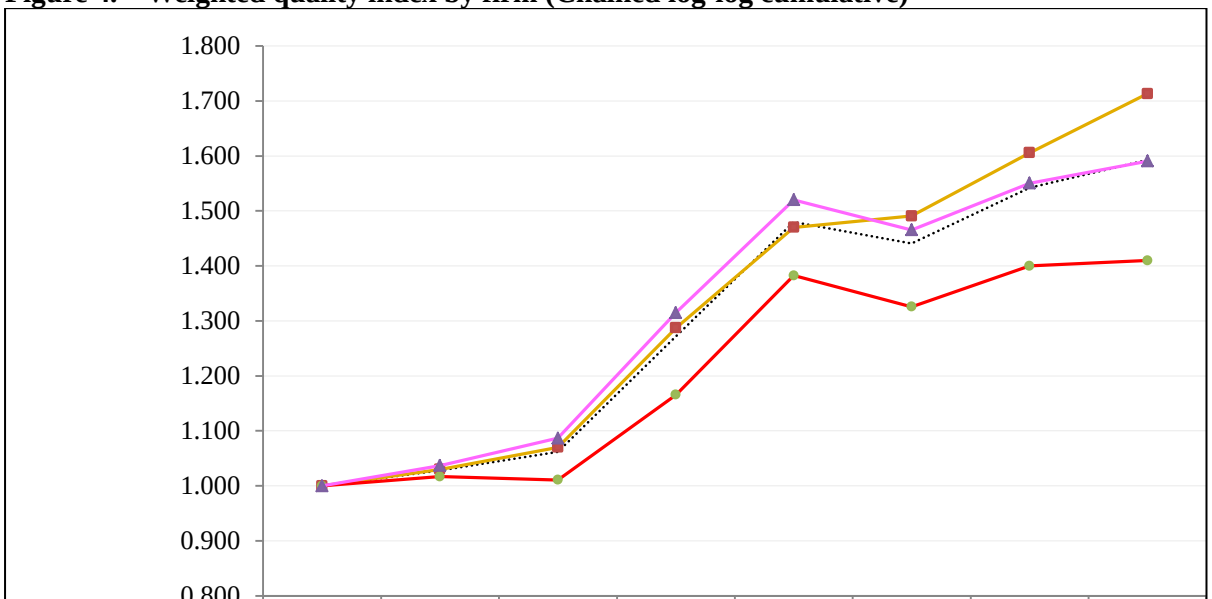
	2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017
Total	1.000	0.946 (-5.4%)	0.946 (-0.1%)	0.730 (-22.8%)	0.763 (4.5%)	1.032 (35.2%)	0.824 (-20.1%)	1.015 (23.2%)
SK Telecom	1.000	0.944 (-5.6%)	0.940 (-0.4%)	0.727 (-22.7%)	0.777 (6.9%)	0.991 (27.5%)	0.819 (-17.4%)	0.983 (20.0%)
KT	1.000	0.938 (-6.2%)	0.932 (-0.6%)	0.723 (-22.4%)	0.768 (6.2%)	1.043 (35.8%)	0.834 (-20.0%)	1.022 (22.5%)
LGU+	1.000	0.956 (-4.4%)	0.983 (2.8%)	0.759 (-22.8%)	0.748 (-1.4%)	1.048 (40.1%)	0.835 (-20.3%)	1.042 (24.8%)

Figure 3. Weighted time dummy hedonic price index by firm (Chained log-log cumulative)



	2010	2011	2012	2013	2014	2015	2016	2017
Total	1.000	0.946	0.895	0.653	0.499	0.515	0.424	0.431
SK Telecom	1.000	0.944	0.887	0.645	0.501	0.497	0.407	0.400
KT	1.000	0.938	0.874	0.632	0.485	0.506	0.422	0.432
LGU+	1.000	0.956	0.940	0.713	0.534	0.559	0.467	0.486

Figure 4. Weighted quality index by firm (Chained log-log cumulative)



	2010	2011	2012	2013	2014	2015	2016	2017
Total	1.000	1.028	1.062	1.272	1.480	1.441	1.542	1.593
SK Telecom	1.000	1.030	1.070	1.287	1.470	1.491	1.606	1.713
KT	1.000	1.017	1.011	1.166	1.382	1.326	1.400	1.410
LGU+	1.000	1.037	1.087	1.315	1.520	1.465	1.550	1.591

6. Policy implications and discussions

The efficacy of the CPI for mobile phone services is not as durable as before, when it is held that technological improvements instigate new goods biases in the index, as illustrated by our quality-adjusted price index. It is recommended that national statistical agencies allow for the use of hedonics to mitigate the problem, though it is costly.

Our estimates indicate an average price decline of 8.1% per year from 2010 to 2017, which is referred to as a measure of the economic benefits to consumers. The magnitude of the benefits seems allowable to our knowledge. This result is roughly comparable to that of fixed broadband access service in the early years. Stranger & Greenstein (2007) finds an annual price decline of 7.3% between 1996 and 1999 in the US, and Yu & Prud'homme's (2010) log-linear model shows a 14.8% from 1993 to 2000.

The actual gains become even greater when our estimated model takes into consideration the price effects of the Mobile Device Distribution Improvement Act enacted in October, 2014, which was allegedly a 20% cut for the consumers' monthly bills.[8] However, we see the law is related to how handset devices are priced under government's subsidy rules, and thus it has little to do with altering the prices of mobile service plans.

We recommend that policymakers be concerned with seeking more precise information from price movements, rather than just with an absolute value of decline. First, the periods 2010-2017 can be divided into 3 stages in terms of price change. The market experiences the highest rate of price declines at the second stage 2013-2014, where the operators extend unlimited usages to messaging and talk in unison, lowering the overall fee for DATA. We uncover some characteristic factors behind such drastic price decline. Interestingly, the price movements by operators have similarities to each other, as shown in Figure 3. We confine our estimates to a preliminary role of analysis of the pricing behavior by wireless operators, and thus it requires a further research to explain the phenomena

Second, changes in hedonic price indexes cannot be equivalent to changes in a cost of living. Hausman (2003) points out that hedonic regressions do not capture consumer preferences which provide a basis for a cost of living index. He notes that the attributes are determined not only by the price, but importantly by the interactions of consumer preferences, technology and competition in the marketplace. Then he suggests that one way of modeling

[8] Due to the Act, the discount rate rose to 25% in 2017.

hedonic regressions for consumer valuation of a product be to use high frequency quantity data. We admit that our paper is short of measuring the cost of living index for mobile services, though the use of a set of combined quantity data for this paper is somehow drawn to Hausman's (2003) point of view. Therefore, we advise caution for interpretation of the index results, i.e., noting that the absolute size of price change in the estimated indexes is NOT equivalent to measuring the cost of living index. Rather the outcome should be used in a suggestive way.

7. Conclusions

We find that the quality-adjusted price indexes for mobile services decrease at an annual rate of 8.1% from the early years of smartphones in Korea. Recently, the rate of price decline has been sluggish. Our standard price indexes are analogous to the Laspeyres index practiced by the KOSTAT. The hedonic prices for the major wireless operators move together in terms of both timing and size, which instigates competitive concerns for policymakers. However, this outcome at best works as a preliminary analysis for a more detailed future research. The study has a couple of shortcomings that require a further analysis. First, we exclude the Aged/Juvenile service plans for analysis by focusing on the General plan observations in this paper. But the wireless operators have introduced a number of new service products targeted to specific age groups. Thus the inclusion of these service products will improve the validity of estimates, as smartphone ownership amongst the 60+ and -20 age groups increases. Second, we find our weighting scheme improve if we carry out a simulation to illustrate the estimates on various weighting options. Such simulation is useful if we are to deal with the unavailability of quantity or expenditure data, and to find ways to address the sources of bias in the price index.

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