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Quality-Adjusted Prices of Mobile Phone Handsets and Carriers' Product Strategies: The Japanese Case*

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Abstract

By employing the adjacent-period approach, we conducted a hedonic regression analysis and calculated the quarterly quality-adjusted prices (QAPs) of mobile phone handsets marketed by three mobile phone service operators (carriers) between 2002 and 2006 in Japan. We observed (i) a decreasing trend of QAPs for each mobile phone carrier, (ii) a more rapid decrease in the QAPs of the two smaler carriers' handsets relative to that of the largest carrier, and (iii) a turnover cycle of the QAPs between the two smaller carriers. We also discuss these carriers' interdependent product/marketing strategies considering our estimation results.

JEL Classification Numbers : C43, D43, L96
Keywords : quality-adjusted price, adjacent-period hedonic regression, product/marketing strategies

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1 Introduction: Hedonic Regression and QAPs

In this study, we conduct a hedonic regression analysis and investigate the quarterly changes in the quality-adjusted prices (QAPs) of mobile phone handsets marketed by three mobile phone service operators (carriers) between 2002 and 2006 in Japan for each carrier. Our aim is to consider the carriers' interdependent product/marketing strategies considering our estimation results and each carrier's QAP changes.

Mobile phone markets offer legitimate characteristics for the application of hedonic regression to measure QAPs owing to fierce competition as well as significant technological innovations in recent years. In their study of digital cameras, Fehder et al. (2008) commented on this point, but the analysis is still rare. Dewenter et al. (2006) estimated carriers' brand name premiums for mobile phone handsets in the German market. The authors' samples were, however, taken between 1998 and 2003; thus, their analysis could not sufficiently account for the technological advances of third-generation mobile phones with high-speed transmission in large volume. So, we examine the Japanese market where those high-performance mobile phones are widely disseminated.

Hedonic regression analysis was developed through the momentum of an empirical study by Griliches (1961) and a theoretical study by Rosen (1974), and has recently been reconsidered by Pakes (2003) and Diewert (2003). Some of the problems associated with hedonic regression, comprehensively discussed by Triplett (2004), were examined in detail by Yu and Prud'homme (2008). These problems include not only the choice of functional forms and measurement units, but the choice between the use of *pooled* regression with time dummies as opposed to *period-to-period* regression without time dummies. Using the Chow test, these researchers suggested that the estimates of coefficients in hedonic regression with time dummies would be unstable for data pooled over multiple periods, because the coefficients are assumed to be constant for the periods. They also noted, however, that estimates were inefficient owing to the small sample sizes in hedonic regressions conducted separately in each period without time dummies.

To compensate for these defects, as suggested by Triplett (2004), we pooled data from each pair two adjacent time periods and used a time dummy for the later period in each hedonic regression. This *adjacent-period approach* holds the coefficients constant for only two periods, and our large data set solves the inefficiency problem that results from the small sample sizes collected during short adjacent time periods. Throughout this paper, we follow suggestions by Triplett (2004) also in other matters associated with hedonic regression.

There were three mobile phone carriers between 2002 and 2006 in Japan; NTT DoCoMo, au KDDI (formally, au by KDDI), and Vodafone/SoftBank. NTT Do-

CoMo, the largest carrier, had a market share of more than 50% of subscribers during this period, and the other two smaller carriers fiercely competed to gain market share. Subscribers must change mobile phone handsets when they change carriers in the Japanese market, because each carrier provides services to its subscribers exclusive of handsets made for the other carriers. Thus, we can say that each carrier has its *own* handsets.

Our main findings are (i) a decreasing trend of QAPs for each carrier, (ii) a more rapid decrease in the QAPs of au KDDI and Vodafone/SoftBank mobile phone handsets relative to that of NTT DoCoMo, and (iii) a turnover cycle of the QAPs between au KDDI and Vodafone/SoftBank. The QAP decreases can be explained by the introduction of higher performing mobile phone handsets as well as by price decreases. The introduction of new models lowers the value of each carrier's own old models. This *obsolescence effect* partly explains the decreasing trend of QAPs. The competition pressure in oligopolistic markets induces carriers to set reasonable prices even for higher performing new models. In oligopolistic markets, moreover, introducing new models also lowers the value of rivals' old models. This *business-stealing effect* explains a more rapid decrease in QAPs of au KDDI and Vodafone/SoftBank mobile phone handsets and a turnover cycle of QAPs between the two carriers. These findings clarify how fiercely, as well as against NTT DoCoMo with a half of the market share, au KDDI and Vodafone/SoftBank competed to gain the remaining share against each other.

The paper is organized as follows. Section 2 briefly reviews the Japanese mobile phone industry. Section 3 describes the data used for our analysis, including a formal definition of the price of a mobile phone handset marketed between 2002 and 2006 in Japan. An explanation of each variable and its summary statistics are also presented there. Section 4 specifies the hedonic regression model, and Section 5 presents the estimation results for the whole market and for each carrier. In Section 6, we estimate the QAPs of the carriers' handsets and discuss the carriers' product/marketing strategies. Section 7 offers final remarks on the related literature.

2 The Japanese Mobile Phone Industry: a Brief Review

Until mid-2007, awkward charge structures existed for mobile phone handsets and mobile phone services in Japan. Retailers sold mobile phone handsets at a huge discount while receiving a rebate from the mobile phone carrier for each new purchase. In fact, a newly introduced model priced at about ¥50,000 (about $549 at Tokyo on December 13 in 2008) could be sold at retail shops for less than half that, and an older model could very well be sold for merely ¥1 to a new subscriber. The carriers

- NTT DoCoMo, au KDDI, and Vodafone/SoftBank - recouped these rebates from charges for services provided to subscribers, especially call charges, which is why call charges for mobile phones in Japan were higher than in other countries.[1] Because of this rebate system, we cannot use sticker prices alone to calculate the QAPs of handsets sold in Japan. We therefore defined the price of a mobile phone handset, roughly speaking, as the sticker price of a new purchase at a retail shop plus the rebate paid from the carrier to the retailer for each new purchase.

The rebate system facilitated replacement of existing models with the latest higher performing models each time a carrier launched a new or improved service, such as Internet connectivity, which NTT DoCoMo initiated in February 1999, e-mail with photos, which J-Phone (currently SoftBank) launched in November 2000, third-generation high-speed large-volume transmission that NTT DoCoMo began as a trial service in May 2001 and for commercial services in October 2001, Truetone (chaku-uta), which au KDDI started in December 2002, packet transmission, which au KDDI launched in November 2003, and Truetone-Full (chaku-uta full), which au KDDI started in November 2004. These services were followed by such functions as music and movie downloading, a global positioning system (GPS), mobile wallet (FeliCa, Suica, etc), coloring letters with static and animated images (Decomail) and the digital television broadcasting service for mobile phones (wan-segu). All these functions are currently major characteristics of mobile phones in Japan.

Despite this positive side, the rebate system was criticized for not providing subscribers with transparency of the real charges for these new services. In particular, long-term subscribers of the same model felt that they were treated unfairly compared to those who quickly upgraded to a new model because of the unreasonable internal cross-subsidization. Thus, on June 2007, the Ministry of Internal Affairs and Communications, which supervises the Japanese mobile phone industry, issued a final report on the abolition of the rebate system and asked carriers to establish a new charge structure that clearly separates handsets' prices and usage charges, in parallel with the existing charge system, starting in 2008.

In response to the Ministry's guidelines, each carrier established a new charge structure by September 2007 and agreed to completely abolish the traditional charge system by 2010. This government policy was generally welcomed by consumers as it allows them to select a mobile phone handset from a wide variety of models based on each service's price information. Because the pricing of mobile phone handsets is still in a period of transition to the new system, it is important to conduct consistent

[1] According to a March 2008 report by the Ministry of Internal Affairs and Communications, after each carrier started reforming a new fee structure beginning in September 2007, call charges in Tokyo were lowered by an average of 30% compared to those in the previous year.

and quantitative analysis of the changes over time in the QAPs of mobile phone handsets for the period of the traditional charge system.

3 The Data

3.1 Data Sources

We collected data on the prices and characteristics (functions and quality) of 350 models of mobile phone handsets marketed between 2002 and 2006 in Japan.[2] During this period, there were three carriers; NTT DoCoMo, au KDDI, and Vodafone/SoftBank.[3] We studied the period from 2002 to 2006 because commercial services for third-generation mobile phones started after October 2001, and the three carriers established new charge structures in September 2007.

The price data were taken from the Price Survey operated by Impress Inc. on its Mobile Phone Watch Web_site.[4] The Web_site has weekly released the sticker prices of almost all mobile phone handsets in the Japanese domestic market at major volume retailers in Tokyo and Osaka since the second half of 2000. The Price Survey provides a database for the Japanese market that covers the largest number of mobile phone handsets for the longest period of time. We selected price data from January 2002 to December 2006 from among all price data published in the Price Survey. Prices are provided for both new purchases and model changes, but we used the sticker prices of mobile phone handsets only for new purchases in the hedonic regression analysis. We collected data on the rebate from the financial report that each carrier publishes every quarter.

As stated in Section 2, the real price of a mobile phone handset is approximately the sticker price plus the amount of the carrier's rebate. We assumed that a mobile phone handset has a lifetime of 24 months. Eventually, we defined the price of a mobile phone handset as the *average monthly payment* of the total amount of the sticker price of a new purchase at retail shops and the rebate paid by the carrier to the retailer for each new purchase, i.e.,

$$\text{price of a handset} = (\text{sticker price} + \text{rebate})/24.$$

[2]Personal digital assistants (PDAs) with phonetic functions, so called "smartphones", were excluded from our hedonic analysis. They are widely recognized not as mobile phones but as products with an information terminal function. NTT DoCoMo started to sell BlackBerry smartphones in August 2008 for personal use (in September 2006 for business use), competing against the introduction of the iPhone by SoftBank in July 2008. The smartphone market is still small in Japan, and there were not sufficient data available for the period we studied.

[3]Another carrier, e-Mobile started its data communication services on 31 March 2007 and call services on 28 March 2008.

[4]The Web address is `http://k-tai.impress.co.jp`

Data on functions and quality were collected from the Mobile Phone New Products SHOWCASE on the Mobile Phone Watch Web_site, the 2008 edition of the White Paper on Mobile Phones, and the Mobyrent Database operated by CELLANT Corporation.

3.2 Descriptive Statistics

Table 1 lists the major characteristics of the mobile phone handsets that we used in this study. In our hedonic regression, we also took into account information about the handset's weight, size (height, width, and depth), manufacturers, and other characteristics. Table 2 shows a list of manufacturers and their market shares. Summary statistics of the major characteristics are presented in Table 3. The values shown are the averages in each quarter in the pooled samples for all carriers, and the value of 0 indicates that the corresponding function was not yet installed in mobile phone handsets. We briefly review the statistics of the characteristics (except *age*, *flash*, and *qr*) listed in Table 3 below.[5] For samples disaggregated by carrier, the estimated impacts of *age* on price is discussed in detail in Section 5.

The transmission speed (*trans_speed*) consistently increased throughout the period from about 50 kbps in the first half of 2002 to about 750 kbps in the second half of 2006. Increased transmission speed presumably went hand-in-hand with the transition from second- to third-generation in mobile phones. Data transmission speed increased remarkably since 2004, which coincides with the introduction of NTT DoCoMo's third-generation FOMA 900 series.

The pixel count for mobile-phone cameras (*camera*) also consistently increased throughout the period. Mobile-phone cameras had less than 3 megapixels in the first half of 2002. The count exceeded 100 megapixels in 2004 and subsequently reached about 170 megapixels in the second half of 2006. The increase in pixel count, however, tended to slow down in 2006.

The resolution of mobile phone screens (*screen*) also consistently increased, but the increase was not as large as that for mobile phone cameras. That is probably because the pictures taken by mobile phone cameras can be seen and edited by other digital equipments including personal computers. The Japanese carriers, however, started a digital television broadcasting service for mobile phones (wan-segu service) on 1 April 2006 within limited areas, and the service areas are being gradually expanded. So, the pixel count for mobile phone screens may increase more rapidly in the future with the dissemination of the wan-segu service and further developments of liquid crystal technology.

[5] QR (Quick Response) code, denoted by *qr* as a dummy variable in Table 1, is a two-dimensional bar code (matrix code) invented by a Japanese company Denso-Wave in 1994.

Table 1: Definition of Major Characteristics (Variables)

variable name	description
speed	transmission speed (kbps)
camera	camera resolution (megapixel)
screen	screen resolution (megapixel)
duration	call duration (minutes)
ringtone	number of polyphonic ringtones
age	elapsed periods (quarters) after the first release
g3	third-generation dummy
java	Java application compatibility dummy
truetone	truetone dummy
truetone_full	truetone-full dummy
flash	Adobe Flash application dummy
qr	QR (Quick Response) code dummy
felica	FeliCa dummy
suica	mobile Suica dummy
full_browser	full-browser dummy
gps	gps dummy
decomail	Decomail dummy
movie	movie compatibility dummy
music	music compatibility dummy
radio	FM radio compatibility dummy
tv	TV viewer dummy
location	location: 1 if store is located in Tokyo; 0 if in Osaka

NOTE: Some characteristics (incl. weight and size) are omitted in this table.

Battery duration, as indicated by talk time (*duration*), decreased slightly in 2002, but gradually increased thereafter. The total increase was about 30 minutes from 2003 to 2006. The decreasing trend in 2002 is presumably attributable to the introduction of early models of NTT DoCoMo's third-generation mobile phones, which consumed more power and reduced the talk time.

Polyphonic ringtones (*ringtone*) increased from about 20 in the first half of 2002 to about 80 in the second half of 2006, a four-fold increase.

Because we used a dummy variable ($g3$) for third generation, we were able to observe the transition from second- to third-generation mobile phones. Third-generation mobile phone handsets accounted for 10% of all handsets in 2002, but its share increased to nearly 70% by the end of 2006. The share increased drastically during 2002 and 2003, because all new models introduced by au KDDI were third-generation mobile phones.

The share of Java application-compatible (*java*) mobile phones increased almost consistently throughout the study period. The technology for Java application compatibility in mobile phones is not particularly new. It was available for more than

Table 2: Market Share Distribution of Mobile Phone Manufacturers

Producer	Share (percent)	Producer	Share (percent)
CASIO	3.55	DENSO	0.19
FUJITSU	8.93	HITACHI	3.06
JRC	0.47	KENWOOD	0.31
KOKUSAI	0.11	KYOCERA	4.06
LG	0.29	MITSUBISHI	7.96
Motorola	0.33	NEC	11.86
NOKIA	1.38	PANTECH	0.7
Panasonic	9.8	Pioneer	0.02
SAMSUNG	0.49	SANYO	11.52
SHARP	14.09	SONY	0.88
SonyEricsson	7.94	TOSHIBA	12.06

half of the handsets marketed even in the first half of 2002, and by the end of 2006, more than 90% of new handsets were compatible with Java applications.

Truetone (*truetone*, chaku-uta) is a service that transforms the ringtone of a mobile phone into a piece of music. Truetone-Full (*truetone_full*, chaku-uta full) is an extended version of Truetone, which covers almost the full length of a song. In December 2002, au KDDI launched its Truetone service, and it started offering the Truetone-Full service in November 2004. In the initial stage, only some au KDDI mobile phone handsets offered the Truetone service. As the service exploded in popularity, however, other carriers launched the same service. Vodafone/SoftBank and NTT DoCoMo followed in 2005 and 2006, respectively. The percentage of handsets supporting Truetone or Truetone-Full increased dramatically, from less than 30% in 2003 to more than 90% in the second half of 2006.

Mobile phones equipped with FeliCa (*felica*) incorporate a noncontact IC chip developed by Sony Corp., and mobile Suica (*suica*) is an electronic money service for transport facilities for mobile phones equipped with FeliCa. FeliCa and mobile Suica are relatively new services. The former started in July 2004 and the latter began in January 2006. Both services spread rapidly within a few years, and by the second half of 2006, about 60% of handsets were equipped with one or the other.

The full browser function (*full_browser*) is also a relatively new feature, which allows the mobile phone user to browse Web_sites designed for PCs. The feature was introduced in the first half of 2005 as the data transmission speed of mobile phones increased. The popularity of the full browser function grew rapidly, and about 30% of new mobile phone handsets had this function in 2006.

The global positioning system (*gps*) function was incorporated in mobile phones relatively early, but this feature did not become popular as rapidly as other functions. In fact, the percentage of handsets with the GPS function grew from 10% in 2002

Table 3: Summary Statistics of Mobile Phone Characteristics

	speed	camera	screen	duration	ringtone	g3	java	truetone	truetone_full	flash
2002 Q1	50.19	2.51	16.28	143.86	17.38	0.10	0.56	0	0	0
2002 Q2	56.02	5.29	17.57	133.34	21.75	0.22	0.61	0	0	0
2002 Q3	58.67	6.79	18.85	130.59	25.67	0.25	0.58	0	0	0
2002 Q4	77.68	10.40	20.40	130.24	30.67	0.34	0.62	0.02	0	0
2003 Q1	80.52	14.50	23.95	133.67	33.89	0.34	0.65	0.07	0	0
2003 Q2	87.69	21.78	28.23	136.69	35.31	0.38	0.56	0.17	0	0.02
2003 Q3	99.25	33.51	36.64	138.12	39.29	0.39	0.69	0.25	0	0.12
2003 Q4	112.25	45.49	44.45	140.99	42.15	0.37	0.71	0.28	0	0.18
2004 Q1	200.29	66.87	55.85	144.39	46.68	0.41	0.78	0.32	0	0.28
2004 Q2	275.69	79.78	59.23	146.31	48.37	0.50	0.77	0.43	0	0.31
2004 Q3	318.31	100.29	64.45	147.48	50.75	0.50	0.79	0.51	0	0.37
2004 Q4	431.02	98.03	63.65	149.39	51.72	0.56	0.77	0.58	0.02	0.38
2005 Q1	496.32	112.28	65.61	152.87	55.23	0.55	0.81	0.70	0.09	0.53
2005 Q2	531.99	114.73	66.61	154.25	57.24	0.54	0.83	0.72	0.14	0.63
2005 Q3	579.75	133.10	71.83	156.31	60.42	0.61	0.88	0.78	0.17	0.70
2005 Q4	605.34	139.17	73.77	157.11	62.90	0.67	0.89	0.86	0.21	0.72
2006 Q1	657.81	156.85	75.31	160.30	70.75	0.70	0.92	0.92	0.28	0.76
2006 Q2	661.93	163.89	77.61	162.46	75.81	0.69	0.95	0.89	0.33	0.77
2006 Q3	721.65	167.49	78.34	165.06	79.97	0.71	0.94	0.90	0.37	0.77
2006 Q4	757.60	169.57	83.66	166.83	81.66	0.69	0.92	0.91	0.42	0.78

	qr	felica	suica	full_browser	gps	decomail	movie	music	radio	tv
2002 Q1	0	0	0	0	0.10	0	0.04	0.01	0	0.04
2002 Q2	0	0	0	0	0.17	0	0.05	0.03	0	0.05
2002 Q3	0.01	0	0	0	0.16	0	0.06	0.03	0	0.05
2002 Q4	0.05	0	0	0	0.15	0	0.10	0.05	0	0.08
2003 Q1	0.06	0	0	0	0.13	0	0.19	0.04	0	0.05
2003 Q2	0.10	0	0	0	0.17	0	0.28	0.04	0	0.05
2003 Q3	0.12	0	0	0	0.20	0	0.37	0.03	0	0.06
2003 Q4	0.20	0	0	0	0.23	0	0.37	0.04	0	0.07
2004 Q1	0.34	0	0	0	0.24	0	0.41	0.05	0.02	0.12
2004 Q2	0.43	0	0	0	0.28	0	0.50	0.06	0.03	0.18
2004 Q3	0.60	0.05	0	0	0.27	0	0.50	0.11	0.06	0.18
2004 Q4	0.57	0.08	0	0	0.28	0.01	0.57	0.11	0.08	0.22
2005 Q1	0.66	0.11	0	0.02	0.25	0.08	0.66	0.16	0.11	0.35
2005 Q2	0.75	0.14	0.01	0.02	0.24	0.18	0.68	0.20	0.15	0.40
2005 Q3	0.83	0.19	0.05	0.06	0.27	0.26	0.72	0.24	0.14	0.41
2005 Q4	0.84	0.19	0.11	0.08	0.30	0.30	0.81	0.29	0.17	0.50
2006 Q1	0.86	0.28	0.19	0.13	0.34	0.32	0.85	0.44	0.23	0.51
2006 Q2	0.84	0.33	0.24	0.15	0.33	0.35	0.88	0.54	0.24	0.57
2006 Q3	0.85	0.34	0.27	0.25	0.34	0.37	0.91	0.64	0.28	0.61
2006 Q4	0.83	0.35	0.29	0.33	0.34	0.40	0.92	0.64	0.27	0.61

NOTE: A value of 0 indicates that the corresponding function was not installed in that period.

to 34% in 2006. Most au KDDI mobile phone handsets have the GPS function, whereas almost all of the handsets marketed by the other two carriers did not.

Decomail (*decomail*) is a service that enables the use of more advanced e-mail features, including static and animated images, by supporting the compact HTML standard (cHTML). This service was added to NTT DoCoMo mobile phones in late 2004, and about 40% of mobile phones had this feature in 2006. Initially, only NTT DoCoMo mobile phones offered this service, but au KDDI started offering the same service in late 2006. Since then, Decomail has rapidly become popular in Japan as a mobile phone function.[6]

Movie-compatible (*movie*) and music-compatible (*music*) functions have been incorporated in mobile phones since early 2002. The percentage of mobile phones with movie compatibility increased steadily since 2002 to reach more than 90%, whereas the percentage of music-compatible mobile phones increased rapidly after 2004, to about 65%. Music compatibility lagged behind movie compatibility because the music distribution system was not established until 2004. The rapid spread of music-compatible mobile phones is closely related to the substantial recent development of the music distribution systems and services after 2005.

FM radio compatibility (*radio*) was first incorporated by au KDDI first in the second half of 2003, followed by Vodafone/SoftBank in the second half of 2004 and NTT DoCoMo in the first half of 2006. Because each carrier adopted a different policy on FM radio compatibility, only 25% of mobile phones on the market were FM radio-compatible in the second half of 2006.

NTT DoCoMo first incorporated the television function (*tv*) in its mobile phone handsets as early as the first half of 2002, but the television function did not spread widely because both au KDDI and Vodafone/SoftBank decided against incorporating this feature as a standard function. In fact, it was incorporated in no more than 60% of handsets in the market in the second half of 2006.

Figure 1 shows the average price (monthly payment) for all mobile phone handsets for all carriers in each quarter from 2002 to 2006. The average fluctuated greatly by more than ¥300 per unit during the study period. Figure 2 shows that the relative highs and lows of the average prices did not follow the same trends for the individual carriers. All carriers lowered the average prices from 2002 to the second half of 2003, but there was no price fluctuation common to each carrier thereafter. NTT DoCoMo maintained relatively high prices even after it introduced third-generation mobile phones, whereas au KDDI lowered the average prices after that introduction.

[6]In July 2008, SoftBank began selling the Apple iPhone 3G, but the sales have not increased as much as expected. One of the reasons is that the phone lacks many popular functions, such as mobile wallet (FeliCa and Suica), Decomail, and digital television broadcasting service (wan-segu).

Figure 1: Average Mobile Phone Price (Monthly Payment) for All Carriers

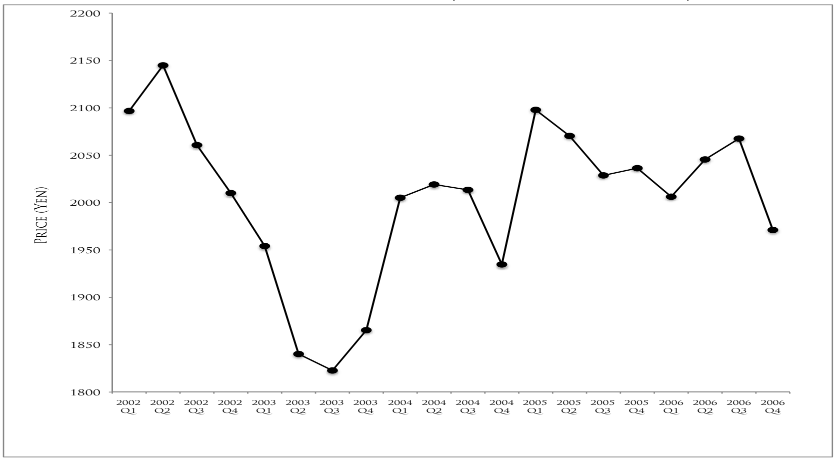
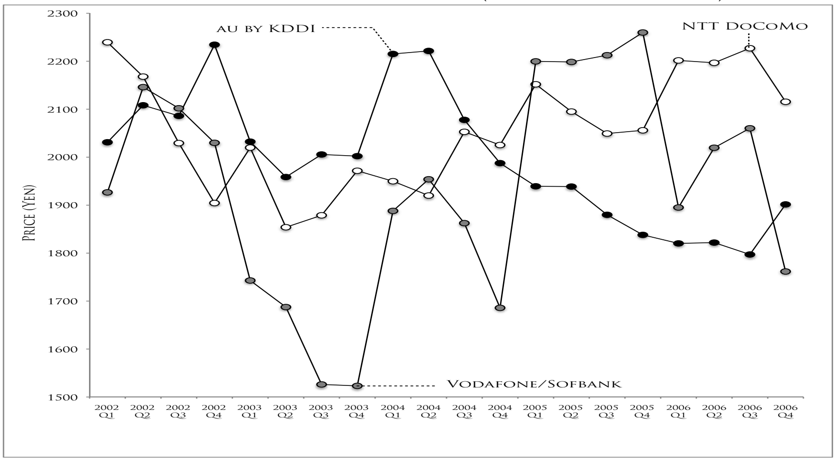


Figure 2: Average Mobile Phone Price (Monthly Payment) by Carrier



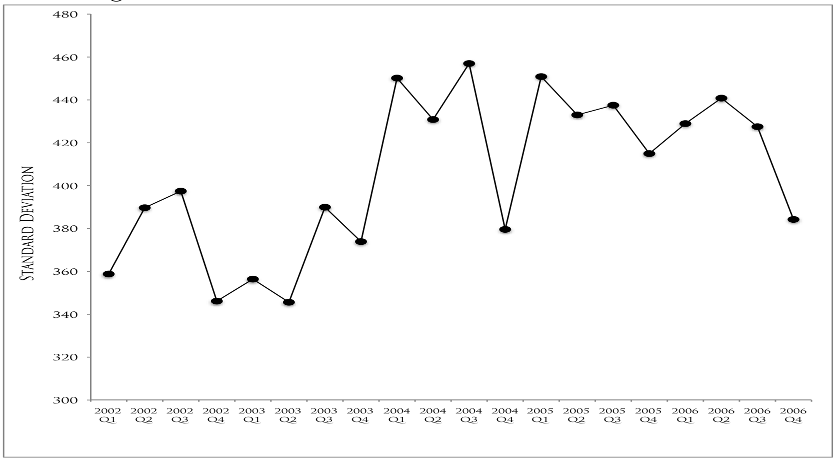
Vodafone/SoftBank often increased the average prices drastically from the second half of 2003 to the end of 2005, but lowered those prices in 2006.

Figures 3 shows the standard deviation of mobile phone prices (monthly payment) by quarter. The prices became more dispersed in every quarter after 2003. A sharp contrast in price can be seen in these figures before and after 2003, the year in which third-generation mobile phones began to be more widely disseminated.

4 The Empirical Model: the Adjacent-Period Approach

We conducted a hedonic regression analysis that explicitly controls for the change in characteristics to compute the QAP of mobile phone handsets. The baseline model is represented by the following regression model which relates the logarithm of the price p_{it} of a handset model i at period t with various characteristics:

Figure 3: Standard Deviation of Mobile Phone Prices



$$\log(p_{it}) = \beta_0 + \sum_{k=1}^{K} \beta_{1k} \log(x_{ki}) + \sum_{l=1}^{L} \beta_{2l} z_{li} + \sum_{m=1}^{M} \gamma_m w_{mit} + \epsilon_{it}, \tag{1}$$

where x_{ki} represents a vector of the quantitative characteristics and z_{li} represents a vector of the qualitative characteristics of mobile phone model i. Both x_{ki} and z_{li} are time-invariant, but w_{mit} represents a vector of the time-varying characteristics of the model i. The regression coefficients β_{1k} and β_{2l} are often called the *implicit prices* of characteristics x_{ki} and z_{li}, respectively. They are interpreted as the prices charged and paid for a one-unit increment of those characteristics.

Price-cost markups will bias the coefficients estimated by hedonic regressions when the markups are an unobserved variable. Feenstra (1995) considered the choice of functional forms for hedonic regressions in such a situation, and Pakes (2003) further investigated this problem.[7] There are two sources of markups; one by manufacturers and the other by carriers. There were as many as 22 manufacturers of mobile phone handsets, and their market shares are small (Table 2). Thus, we can infer that the price-cost markups by manufacturers are not large. The competition pressure in oligopolistic markets will induce carriers to set reasonable prices. Following the practice of many previous studies, we therefore used a log-log specification for the quantitative variable x_{ki} and a semi-log specification for the qualitative variable z_{li} so that we discuss the markups by carriers based on the estimation results.

We added quarterly time dummies to the baseline hedonic regression model (1):

[7] See Anstine (2004) for an excellent discussion of this matter. In a more general context, Benkard and Bajari (2005) proposed the use of factor analysis methods to correct the bias owing to unobserved characteristics.

$$\log(p_{it}) = \beta_0 + \sum_{k=1}^{K} \beta_{1k} \log(x_{ki}) + \sum_{l=1}^{L} \beta_{2l} z_{li} + \sum_{m=1}^{M} \gamma_m w_{mit} + \sum_{q=1}^{Q} \delta_q D_q + \epsilon_{it}, \qquad (2)$$

where D_q is a quarterly dummy that is defined by

$$D_q = \begin{cases} 1 & \text{if period } t \text{ belongs to } q \text{ quarter,} \\ 0 & \text{otherwise.} \end{cases}$$

There are 19 time dummies for the second quarter of 2002 to the fourth quarter of 2006. (The first quarter of 2002 is the base quarter for the QAP index.) The exponential value of the coefficient of the time dummies, $\exp(\delta_q)$, measures the price change in mobile phone handsets between the base quarter and q-th quarter, if we take into account all the changes in characteristics that occurred during the period.

Equation (2) is called a *pooled* regression hedonic model. Despite the use in many studies, a well-known difficulty with this type of model is that the regression coefficients (implicit prices) are assumed to be constant over the pooled periods. This assumption has been criticized by many researchers, as noted in Section 1. Thus, we employed the *adjacent-period* hedonic regression model (Triplett (2004)). We pooled data from two adjacent quarters, used a time dummy for the later quarter in hedonic regression, and computed the QAP for the later quarter. To compute the QAP for the next quarter, the data were pooled from the next two adjacent quarters so that the later period in the previous regression becomes the earlier period in the next regresssion. This approach holds the coefficients constant for only two periods.

The study period was partitioned into a vector $[q_1, \cdots, q_S]$ of 20 quarters, where q_s represents the s-th quarter. By pooling the data from two quarters $[q_{s-1}, q_s]$ $(s \neq 1)$, the adjacent-period hedonic regression model can be represented by

$$\log(p_{it}) = \beta_0 + \sum_{k=1}^{K} \beta_{1k} \log(x_{ki}) + \sum_{l=1}^{S} \beta_{2l} z_{li} + \sum_{m=1}^{M} \gamma_m w_{mit} + \delta_{q_s} D_{q_s} + \epsilon_{it}. \qquad (3)$$

5 The Estimation Results

Tables 4 to 11 in the Appendix present the estimation results. In each table, the columns represent the pairs of two adjacent quarters in which the data were pooled and the rows represent major mobile phone characteristics as explanatory variables for determining the prices of handsets in the corresponding two adjacent quarters. Equation (3) contains explanatory variables such as weight and size of mobile phone handsets and dummies for mobile phone manufacturers, but we omitted to show the estimates of their coefficients in the tables. In what follows, the k-th quarter in each year was abbreviated to Qk ($k = 1, 2, 3, 4$).

5.1 Pooled Samples: Market Trends

Tables 4 and 5 show the estimation results of the adjacent-period hedonic regression for the pooled samples of all carriers. Hedonic regressions often have a low goodness of fit as measured by the adjusted coefficient $\bar{R}^2$ of determination, indicating that there are unobserved characteristics. For example, Pakes (2003) examined many functional forms in the pooled hedonic regression and reported the $\bar{R}^2$'s for PCs that ranged from 0.26 to 0.52. In this study, the $\bar{R}^2$ for mobile phone handsets was 0.55 in the pooled hedonic regression (model (2)). Moreover, in all adjacent-period hedonic regressions for the pooled samples, the $\bar{R}^2$'s ranged from 0.55 to 0.96 (Tables 4 and 5), so the fit of model (3) is relatively good in each regression. Therefore, even if it exixts, the bias owing to unobserved characteristics is not serious.

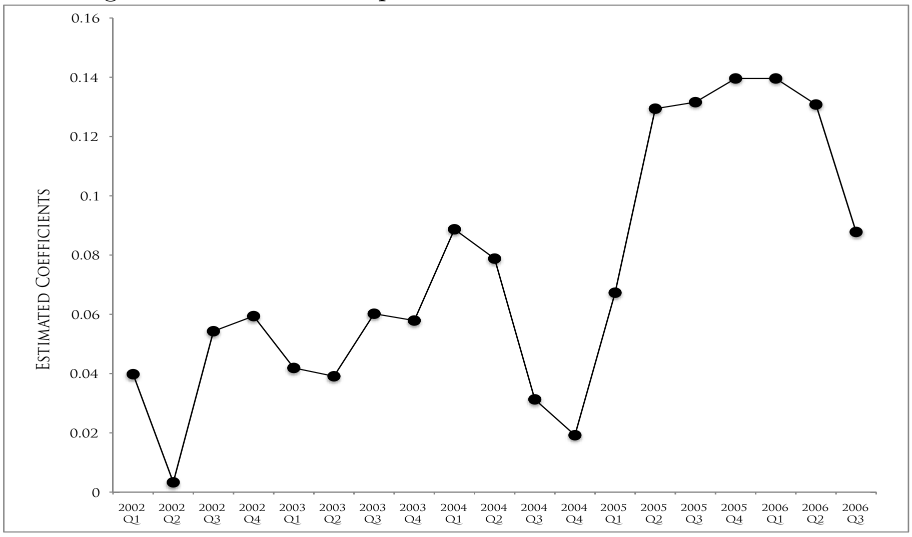
It should be noted, however, that model (3) had a better fit in the earlier periods. Thus, attention must be paid when interpreting the estimation results from the latter half of the study period because the characteristics selected by the model have a lower power of explanation. The factors that may decrease the power of explanation are discussed in the interpretation of the estimation results for each carrier.

Transmission speed ($\log(speed)$) had a significantly positive effect on mobile phone prices in all estimation results between 2002 and 2004, but the signs of the coefficients became unstable after 2005, even though they were still all significant (at the 1% level) except in Q3 in 2005. Presumably this basic factor of mobile phone price was replaced by other characteristics. For example, the music function became more widespread after 2005, and it is closely correlated to transmission speed.

The pixel count of mobile phone cameras ($\log(camera)$) also had a significantly positive effect on mobile phone prices in almost all regression results, i.e., the prices increased as the camera pixel count increased. The elasticity increased from 0.04 in Q1-Q2 in 2002 to 0.14 in Q1-Q2 in 2006. Interestingly, the elasticity of the camera pixel count that contributes to mobile phone prices grew stronger as time advanced. Figure 4 verifies this relationship by plotting the implied prices for the camera pixel count. The increase in the contribution of camera pixel count to mobile phone prices, however, slowed down after Q2 in 2005 and turned negative after Q2 in 2006.

Our interpretation of these results is that the camera pixel count was the major competitive factor in the decision on setting mobile phone prices and contributed to the fierce competition between mobile phone manufacturers until Q4 in 2005. Camera pixel count was, however, replaced by image quality functions (e.g., shake prevention) as competitive factors that determined mobile phone prices in 2006

Figure 4: Estimated Impacts of Camera Resolution on Price



when the pixel count exceeded 100 megapixels. The influence of screen resolution (log(*screen*)) on mobile phone prices was sometimes significant, but the direction was not stable. As a result, we were not able to construct a significant economic interpretation of how screen resolution affects mobile phone prices.

The battery duration in talk time (log(*duration*)) had a positive influence on mobile phone prices until 2003 but a negative influence thereafter. This indicates that the battery duration was a major factor for mobile phone prices in 2002 and 2003, but the differences in battery performance were no longer a decisive factor as mobile phone technology developed in the second half of the study period.

The influence of qualitative variables and dummies on mobile phone prices was not consistent throughout the period. Java application compatibility ($java$), FeliCa compatibility ($felica$), mobile Suica compatibility (*suica*), and full browser compatibility ($full\_browser$) each had a significantly positive influence on the prices at the time the feature was introduced, but the influence decreased as time passed.

GPS (*gps*) and music (*music*) functions had a positive influence on mobile phone prices in the later periods. We did not, however, observe a clear relationship between mobile phone prices and such characteristics as polyphonic ringtones (*ringtone*), third-generation model ($g3$), Truetone (*truetone*), Truetone Full ($truetone\_full$), Flash ($flash$), QR code (*qr*), Decomail (*decomail*), and movie function (*movie*).

The coefficient of *age* (the elapsed time after the introduction of a mobile phone as a new model) was significantly negative throughout the period, supporting the anticipated result that the price of a mobile phone handset decreases as it becomes obsolete. The estimation results showed that the retail price of a mobile phone drops by $4 - 10\%$ after it is marketed. The coefficient of *location*, which represents the price difference between Tokyo and Osaka, was found to be significantly negative after Q2 in 2004, indicating that mobile phone handsets were sold at lower prices in Tokyo than in Osaka after that time.

The time dummy had a significantly negative influence on the prices (at the 1% level) in all quarters except for Q4 in 2003. Thus, even after controlling for the characteristics, mobile phone prices decreased as time advanced. We discuss this in detail in Section 6.

5.2 Samples Disaggregated by Carrier: NTT vs au

Tables 6 to 11 show the estimation results for each carrier. Some variables were dropped when the fluctuations necessary for regression were not obtained, especially in the early periods, i.e., when a feature corresponding to the variable was not offered or the feature was incorporated into any mobile phone handsets by the same carrier.

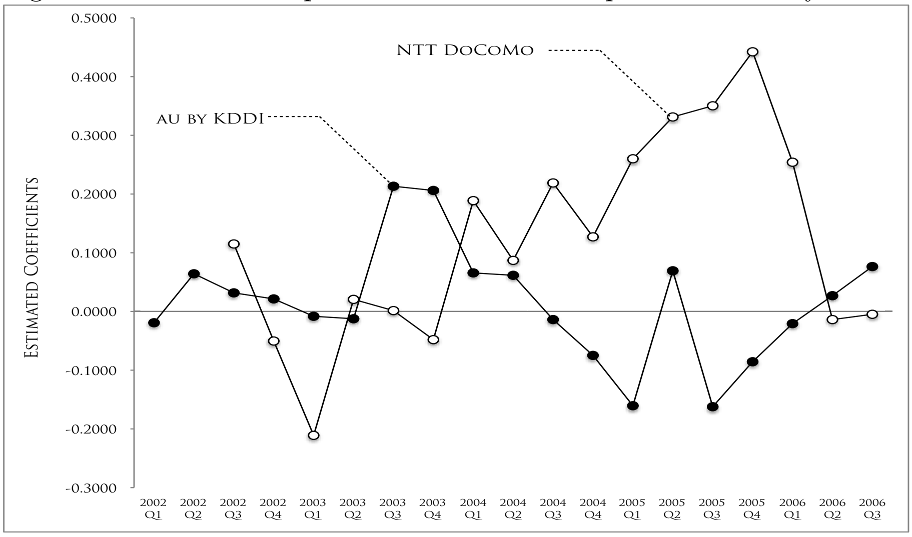
In this subsection, our discussion is focused on the estimation results and differences in product/marketing strategies for NTT DoCoMo and au KDDI mobile phone handsets because there were several contrasting results in the hedonic regression analysis, most notably in the goodness of fit of the models, transmission speed, influence of age, and negative coefficients for other characteristics.

The goodness of fit of the model as measured by $\bar{R}^2$ was excellent in the regression analysis of NTT DoCoMo mobile phones, with values ranging from 0.67 to 0.89, whereas that of au KDDI mobile phones was poor, with values ranging from 0.46 to 0.89. The regression results for NTT DoCoMo showed relatively good results in the accuracy of the models, especially since 2004, whereas those for au KDDI deteriorated as time advanced. The difference in the goodness of fit of the two samples grew greater.[8]

The transmission speed had a consistently positive influence on the prices of NTT DoCoMo mobile phones, but there was no strong correlation between transmission speed and price for au KDDI mobile phones. As can be seen in Figure 5, the influence of transmission speed on price for NTT DoCoMo mobile phones increased throughout the period until the second half of 2006, whereas the influence of transmission speed on price for au KDDI mobile phones remained almost constant. These results presumably mean that consumers bought NTT DoCoMo mobile phones because of basic characteristics including transmission speed, while consumers bought au KDDI mobile phones without depending on characteristics that we consider to be the basic factors of a mobile phone, especially since 2004.

[8]In the pooled hedonic regression (model (2)), the estimated $\bar{R}^2$'s were 0.70 for NTT DoCoMo's handsets, 0.43 for au KDDI, and 0.77 for Vodafone/SoftBank.

Figure 5: Estimated Impacts of Transmission Speed on Price by Carrier

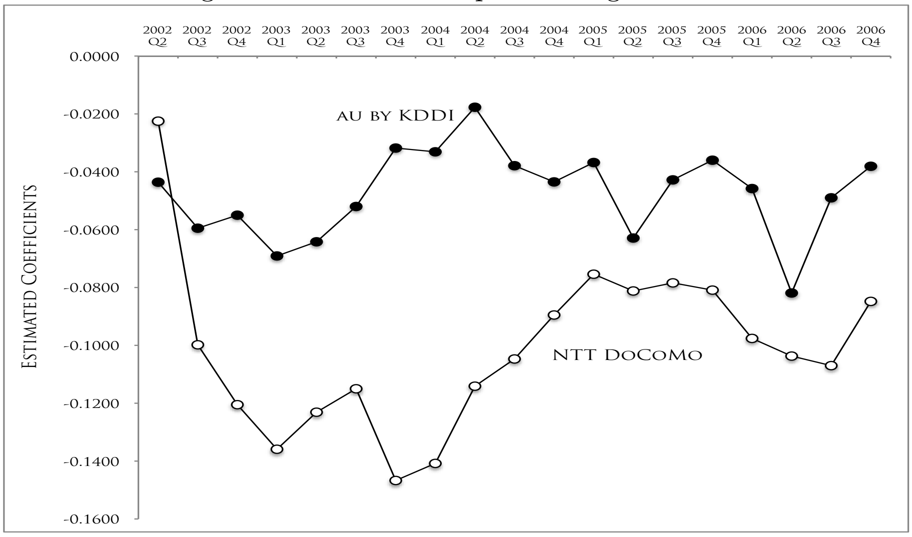


There are two points that may explain why, during the second half of the period, transmission speed was not a constituent factor of the prices of au KDDI mobile phones. First, our hedonic regression may have excluded some important alternative factors, e.g., *design*. During this period, au KDDI had succeeded in establishing a reputation of creating elegantly designed mobile phones.[9] It is, nevertheless, difficult to measure design itself as a numerical value for regression analysis. Second, the prices of au KDDI mobile phones possibly reflects a complex product/marketing strategy. In 2004, au KDDI adopted a strategy to completely enclose customers by emphasizing the diverse contents and services offered in their CDMA2000 1X third-generation system. The prices of au KDDI mobile phones was not determined by the expense structure of characteristics alone, but rather au KDDI presumably decided to set prices in consideration of the distribution of customers' diverse preferences. Figure 5 also shows the rapid decrease in the estimated impact of transmission speed on the prices of NTT DoCoMo mobile phones, which was most likely due to a change of NTT DoCoMo's product/marketing strategy at that point in time.

There was also a clear difference in the influence of age on price between NTT DoCoMo and au KDDI mobile phones. Although the prices of both carriers' mobile phones decreased as time elapsed after the first release, the prices of NTT DoCoMo mobile phones demonstrated a larger decrease (Figure 6), most likely as a result of a shorter cycle of new product introduction. In the early periods of the transition to third-generation mobile phones, NTT DoCoMo introduced undeveloped models and revised them many times.

[9]au KDDI headhunted competent industrial designers from other companies during the period.

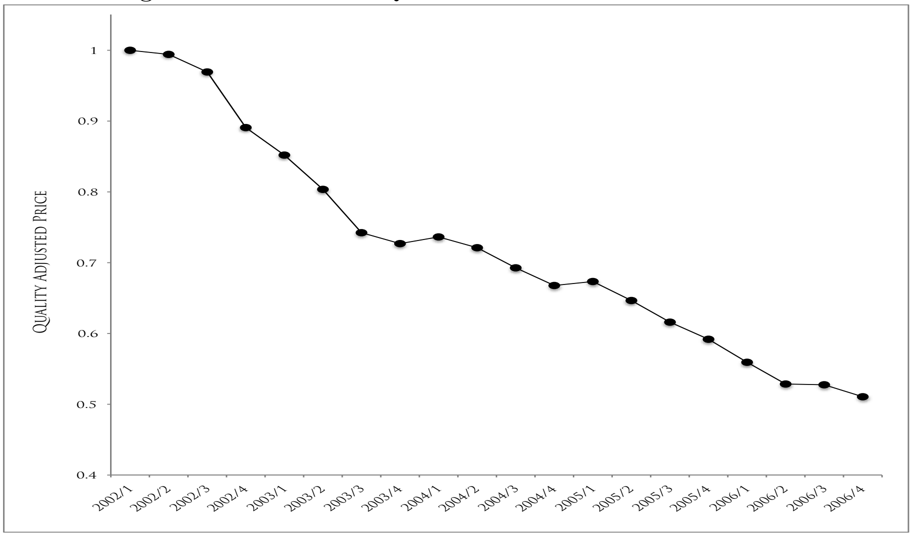
Figure 6: Estimated Impacts of Age on Price



Finally, the estimated coefficients (implicit prices) of some representative characteristics were negative. NTT DoCoMo initially started the Decomail service, and the negative implicit prices of the Decomail compatibility function reflect NTT DoCoMo's strategy to capture customers by this service. The implicit prices of QR code were also negative for NTT DoCoMo's mobile phones in the latter part of the study periods. To gain more subscribers, au KDDI adopted the strategy of featuring a Java application and a music (later with movies) compatibility service called LISMO (au Listen Mobile Service); thus, coefficients of the Java application and music compatibility dummies were negative as a result.

There were other interesting results. We found that music compatibility (*music*) had a positive influence on NTT DoCoMo mobile phones throughout the periods after Q2 in 2004, and the results were stable and significant at the 1% level. Music compatibility also had a positive influence on au KDDI mobile phones in some periods, but the signs did not remain stable. This result may seem strange because of the widespread impression that au by KDDI mobile phones have excellent music-related technology. As noted in Section 4, however, mobile phone prices in oligopolistic markets are determined not only by the costs paid by manufacturers but also the markups by carriers. Accordingly, we can presume that the price decision for au KDDI mobile phones were affected by its complex product/marketing strategy, as noted above. It is remarkable that the coefficient for *location* was not significant in many periods for NTT DoCoMo and au KDDI mobile phones, whereas Vodafone/SoftBank mobile phones were sold at significantly higher prices in Tokyo than in Osaka.

Figure 7: Estimated QAPs for Mobile Phone Handsets



6 Estimating QAPs: Carriers' Product Strategies

We estimated the QAP indices of mobile phone handsets both for the market as a whole and for each carrier based on the adjacent-period hedonic regression (model (3)). As noted in Section 1, the QAP is a price index of subscribers' welfare measured in consideration of product characteristics (functions and quality). Subscribers' welfare improves as QAPs decrease. Requena-Silvente and Walker (2006) used the sales weight to capture the distribution of purchases across handset models in calculating QAPs.[10] Triplett (2004) noted, however, that the main purpose of hedonic regression analysis is to estimate the frontier (hedonic surface) of the price and characteristics of the studied good, so sales or share weighting does not necessarily fit that purpose. Thus, we did not use share weighting.

Given the regression for two adjacent quarters $[q_{s-1}, q_s]$, let $\hat{\delta}_{q_s}$ represent the estimated coefficient of the time dummy variable D_{q_s} in regression model (3). For the partitioned sample periods, $[q_1, \cdots, q_\tau, \cdots, q_S]$, the QAP index of mobile phone handsets at the q_τ quarter as the basis of q_1 quarter is given by

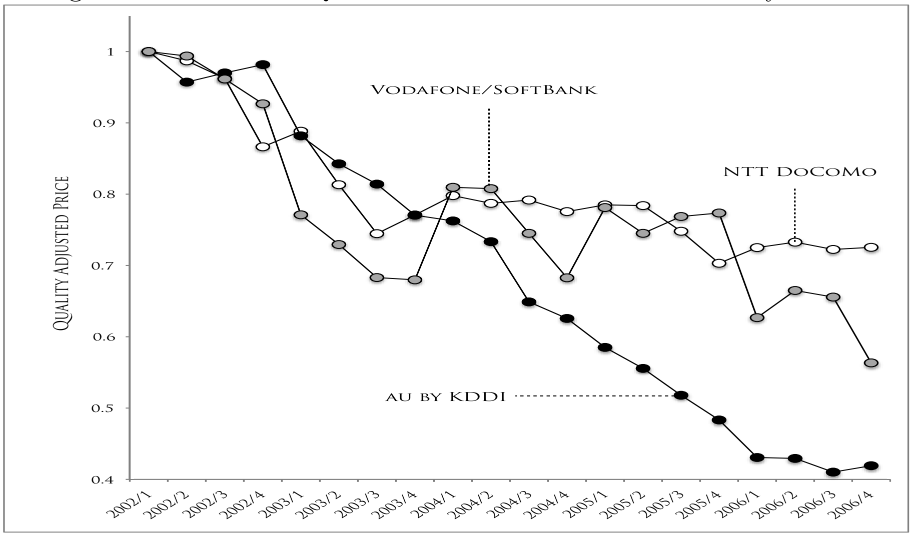
$$\widehat{QAP}_\tau = \prod_{s=2}^{\tau} \exp(\hat{\delta}_{q_s}), \tag{4}$$

for $2 \leq \tau \leq S$.

Figure 7 presents the estimated trend of the QAP index of the mobile phone handsets marketed between Q1 in 2002 and Q4 in 2006 in Japan. It is apparent that

[10]It is usually very difficult to collect the appropriate sales data for that purpose.

Figure 8: Estimated QAPs for Mobile Phone Handsets by Carrier



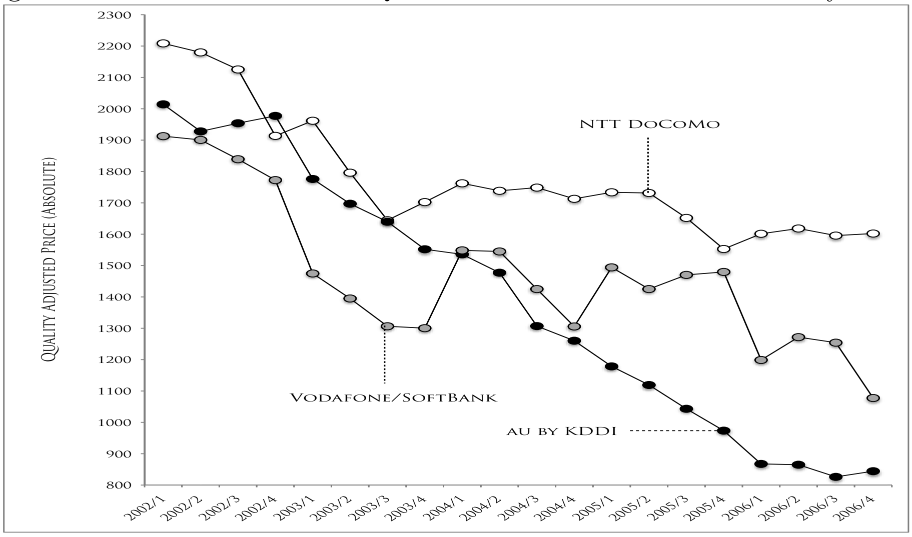
the QAP decreased steadily during this period. The consistent decrease in the QAP index contrasts remarkably with the average retail price of a mobile phone handset, which fluctuated widely during the same period (Figure 1). In particular, the QAP index fell substantially before 2004. For the period between Q1 in 2002 and Q4 in 2004, the QAP index decreased by more than 30% points, which we consider to be driven by the substantive improvement in functions and quality that occurred during those periods. Overall, the QAP index dropped by almost 50% during the entire period.

The rate of decrease in mobile phone QAP differs across carriers (Figure 8). The QAPs of au KDDI and Vodafone/SoftBank mobile phones decreased more rapidly than that of NTT DoCoMo mobile phones. For the 5-year period, the percentage reductions in QAP were about 60% for au KDDI and 40% for Vodafone/SoftBank, whereas it was about 30% for NTT DoCoMo. Thus, the average decrease in QAPs for mobile phone handsets ranged from 6% to 12% per year from 2002 to 2006.

Even though they both decreased by more than that for NTT DoCoMo, the patterns of the QAP indices are remarkably different for au KDDI and Vodafone/SoftBank (Figure 8). The QAP index for au KDDI showed a steady decreased over time, whereas the QAP index for Vodafone/SoftBank showed two periods of substantial price decreases; the first occurred in periods from Q1 to Q3 in 2003, and the second occurred in the periods from Q1 in 2006 to Q4 in 2006.

The QAP index may not, however, be directly comparable across carriers because it only measures the *relative* change in mobile phone prices over time among the mobile phones of the same carrier. We therefore examined another measure, the

Figure 9: Estimated Absolute QAPs for Mobile Phone Handsets by Carrier



absolute QAP, which explicitly allows for the initial price difference during the base period between carriers. For carrier k, the absolute QAP is defined by

$$\widehat{AQAP}_{\tau}^{k} = \bar{p}_1^k \prod_{s=2}^{\tau} \exp(\hat{\delta}_{q_s}^k), \tag{5}$$

where $\bar{p}_1^k$ is the price of a mobile phone of carrier k in the base period and $\hat{\delta}_{q_s}^k$ is the estimated coefficient of the dummy variable D_{q_s} in hedonic regression (model (3)) for carrier k. The absolute QAPs for the three carriers are shown in Figure 9.

After controlling various characteristics, NTT DoCoMo mobile phones were relatively more expensive than au KDDI and Vodafone/SoftBank mobile phones in almost all of the periods. There was a clear *turnover* of QAPs between au KDDI and Vodafone/SoftBank mobile phones in Q1 in 2004. Interestingly, a *cyclic pattern* can be observed between these mobile phone carriers. We can see that the QAP gap between au KDDI and Vodafone/SoftBank mobile phone handsets continued to grow larger in 2004 and 2005, and then started to shrink again in 2006. Although data limitations prevented us from keeping track of the QAP gap after 2006, it appeared that the QAP turnover was likely occur again sometime in 2007.

The QAP decreases can be explained by the introduction of higher performing mobile phone handsets as well as by price decreases. The introduction of new models lowers the value of each carrier's own old models. This *obsolescence effect* partly explains the decreasing trend of QAPs, and the competition pressure in oligopolistic markets induces carriers to set reasonable prices even for higher performing new models. In oligopolistic markets, moreover, introducing new models also lowers the value of rivals' old models. This *business-stealing effect* explains a more rapid decrease in QAPs of au KDDI and Vodafone/SoftBank mobile phone handsets and a turnover cycle of QAPs between the two carriers. These findings clarify how fiercely, as well as against NTT DoCoMo with a half of the market share, au KDDI and Vodafone/SoftBank competed to gain the remaining share against each other.

7 Final Remarks

Our examination of the QAPs of mobile phone handsets showed (i) a decreasing trend of QAPs for each carrier, (ii) a more rapid decrease in the QAPs for au KDDI and Vodafone/SoftBank relative to that of NTT DoCoMo's, and (iii) a turnover cycle of the QAPs between au KDDI and Vodafone/SoftBank.

Fishman and Rob (2002) presented a theoretical explanation for the decreasing trend of QAP from the viewpoint of dynamic R&D of a monopolistic firm. There is, however, no theoretical explanation for how the QAPs of each firm's products are correlated to the other firms in an industry. In Section 4, we discussed the product/marketing strategies of au KDDI and the differences in the impacts of some characteristics on the prices of au KDDI and NTT DoCoMo mobile phones. We expect that a turnover pattern of the QAPs will be explained by a theoretical model with strategic interaction among rival firms in an industry.

A decreasing trend of QAPs has been reported for new cars (Griliches (1961)), software packages (Gandal (1994)), personal computers (Nelson et al. (1994) and Berndt et al. (1995)), mainframe computers (Brown (2000)), and PDAs (Chwelos et al. (2008)). Faced with limited sample sizes, these empirical studies all examined the whole market, and found that QAPs decrease rapidly during the early stages after the introduction of a new product and then the rate of decrease tapers off, or that the faster new products are introduced, the faster the rate of decrease in their QAPs. Our larger data set allowed us in this study to consider carriers' product strategies in view of changes in QAPs of mobile phone handsets for each carrier.

Finally, although we studied mobile phone handsets in this paper, the demand for various mobile phone services in Japan has been reviewed by Iimi (2005) and Ida and Kuroda (2008).

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Table 4: Regression Results: All Carriers (2002Q1-2004Q2)

variable	2002 Q1 2002 Q2	2002 Q2 2002 Q3	2002 Q3 2002 Q4	2002 Q4 2003 Q1	2003 Q1 2003 Q2	2003 Q2 2003 Q3	2003 Q3 2003 Q4	2003 Q4 2004 Q1	2004 Q1 2004 Q2
log(speed)	0.197 ***	0.425 ***	0.197 ***	0.067 ***	0.054 ***	0.111 ***	0.131 ***	0.077 ***	0.076 ***
	(0.024)	(0.060)	(0.030)	(0.011)	(0.013)	(0.012)	(0.007)	(0.007)	(0.006)
log(camera)	0.040 **	0.003	0.054 **	0.059 ***	0.042 ***	0.039 ***	0.060 ***	0.058 ***	0.089 ***
	(0.017)	(0.048)	(0.023)	(0.016)	(0.013)	(0.009)	(0.007)	(0.009)	(0.007)
log(screen)	-0.109	-0.545 ***	0.142 ***	-0.054 **	-0.038 **	-0.011	-0.004	0.026 ***	0.090 ***
	(0.133)	(0.143)	(0.034)	(0.022)	(0.019)	(0.013)	(0.009)	(0.010)	(0.010)
log(duration)		0.936 ***	0.081 *	0.030	0.150 **	0.575 ***	0.206 ***	-0.027	-0.285 ***
		(0.215)	(0.049)	(0.051)	(0.061)	(0.067)	(0.050)	(0.054)	(0.044)
ringtone	0.002 ***	-0.003 ***	-0.001	0.002 **	0.003 ***	0.003 ***	0.000	-0.001	-0.001 ***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
g3		-0.240 ***	0.139 ***	0.128 ***	0.037	-0.123 ***	-0.251 ***		
		(0.069)	(0.029)	(0.029)	(0.032)	(0.030)	(0.037)		
java	0.039 **	-0.085 **	0.026	0.099 ***	0.136 ***	0.085 ***	0.001	0.046 ***	0.106 ***
	(0.019)	(0.037)	(0.019)	(0.017)	(0.020)	(0.012)	(0.009)	(0.011)	(0.011)
truetone			0.122 ***	0.001	-0.001	-0.135 ***	-0.042 **	-0.119 ***	-0.086 ***
			(0.045)	(0.028)	(0.020)	(0.020)	(0.022)	(0.023)	(0.019)
truetone-full									
flash					0.063	0.078 ***	0.150 ***	0.055 ***	-0.091 ***
					(0.041)	(0.018)	(0.013)	(0.015)	(0.013)
qr		0.099 **	0.048 ***	-0.189 ***	-0.239 ***	-0.131 ***	-0.049 ***	0.087 ***	0.079 ***
		(0.040)	(0.024)	(0.024)	(0.024)	(0.014)	(0.012)	(0.013)	(0.011)
felica									
full-browser									
suica									
gps		-0.597 ***	-0.378 ***	-0.072 ***	-0.021	0.012	0.097 ***	0.060 ***	-0.026 *
		(0.080)	(0.059)	(0.021)	(0.021)	(0.016)	(0.013)	(0.014)	(0.013)
decomail									
movie	-0.184 *	-0.135 **	-0.039	-0.178 ***	-0.087 ***	-0.040 **	0.083 ***	0.101 ***	0.136 ***
	(0.110)	(0.059)	(0.027)	(0.026)	(0.025)	(0.020)	(0.029)	(0.027)	(0.024)
music	-0.080 **	-0.119 ***	0.016	0.087 ***	0.069 ***	0.058 **	0.045 ***	0.139 ***	0.020
	(0.034)	(0.031)	(0.025)	(0.021)	(0.025)	(0.019)	(0.019)	(0.020)	(0.016)
radio							0.016	-0.059 **	-0.107 ***
							(0.051)	(0.029)	(0.021)
tv			-0.410 ***	0.059 *	0.050 **	0.004	0.028 *	-0.057 ***	-0.042 ***
			(0.109)	(0.031)	(0.025)	(0.015)	(0.015)	(0.017)	(0.014)
age	-0.040 ***	-0.072 ***	-0.057 ***	-0.103 ***	-0.079 ***	-0.068 ***	-0.062 ***	-0.074 ***	-0.086 ***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.004)	(0.003)	(0.004)	(0.003)
location	-0.001	0.007	0.004	0.001	0.022	0.019	0.010	0.007	0.006
	(0.005)	(0.006)	(0.006)	(0.007)	(0.007)	(0.005)	(0.005)	(0.006)	(0.005)
time dummy	-0.006	-0.025 ***	-0.085 ***	-0.045 ***	-0.059 ***	-0.079 ***	-0.021 ***	0.013 ***	-0.021 ***
	(0.007)	(0.007)	(0.008)	(0.009)	(0.008)	(0.006)	(0.005)	(0.006)	(0.005)
constant	7.583 ***	7.696 ***	5.115 ***	7.505 ***	6.874 ***	4.242 ***	5.903 ***	6.958 ***	7.353 ***
	(1.223)	(0.870)	(0.432)	(0.377)	(0.419)	(0.422)	(0.270)	(0.266)	(0.201)
N	338	463	662	895	1005	1311	1676	1704	1816
$\bar{R}^2$	0.959	0.889	0.733	0.595	0.664	0.798	0.776	0.705	0.765

NOTE: Robust standard errors are in parentheses. $* \ p < .1$. $** \ p < .05$. $*** \ p < .01$.

Table 5: Regression Results: All Carriers (2004Q2-2006Q4)

variable	2004 Q2 2004 Q3	2004 Q3 2004 Q4	2004 Q4 2005 Q1	2005 Q1 2005 Q2	2005 Q2 2005 Q3	2005 Q3 2005 Q4	2005 Q4 2006 Q1	2006 Q1 2006 Q2	2006 Q2 2006 Q3	2006 Q3 2006 Q4
log(speed)	0.071 ***	0.043 ***	0.018 ***	-0.031 ***	-0.002	0.021 ***	0.039 ***	0.039 ***	-0.029 ***	-0.030 ***
	(0.006)	(0.005)	(0.006)	(0.008)	(0.009)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
log(camera)	0.079 ***	0.031 ***	0.019 ***	0.067 ***	0.129 ***	0.132 ***	0.140 ***	0.140 ***	0.131 ***	0.088 ***
	(0.006)	(0.007)	(0.007)	(0.009)	(0.010)	(0.009)	(0.010)	(0.010)	(0.008)	(0.009)
log(screen)	0.056 ***	-0.020	-0.029 **	-0.038 **	0.141 ***	0.249 ***	0.448 ***	0.448 ***	-0.004	-0.056 ***
	(0.010)	(0.012)	(0.014)	(0.019)	(0.023)	(0.025)	(0.037)	(0.037)	(0.017)	(0.015)
log(duration)	-0.199 ***	-0.084 **	-0.080 **	-0.142 ***	-0.139 ***	-0.291 ***	-0.269 ***	-0.269 ***	0.255 ***	0.251 ***
	(0.038)	(0.037)	(0.036)	(0.038)	(0.035)	(0.033)	(0.042)	(0.042)	(0.037)	(0.036)
ringtone	-0.002 ***	-0.001 *	0.000	-0.002 ***	0.001	0.000	0.001 ***	0.001 ***	0.000 **	0.000 ***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
g3		-0.089	-0.091 ***	0.004	-0.072 ***	-0.198 ***	-0.379 ***	-0.379 ***	0.082 ***	0.166 ***
		(0.093)	(0.021)	(0.018)	(0.018)	(0.023)	(0.027)	(0.027)	(0.018)	(0.017)
java	0.086 ***	0.078 ***	0.032 **	-0.038 *	-0.172 ***	-0.134 ***	-0.312 ***	-0.312 ***	-0.180 ***	-0.167 ***
	(0.011)	(0.013)	(0.015)	(0.023)	(0.026)	(0.023)	(0.027)	(0.027)	(0.020)	(0.019)
truetone	0.025 *	-0.011	-0.030 *	0.025	0.184 ***	0.123 ***	-0.070 ***	-0.070 ***	0.043 ***	-0.028
	(0.015)	(0.016)	(0.016)	(0.020)	(0.019)	(0.016)	(0.018)	(0.018)	(0.016)	(0.019)
truetone-full		-0.013	-0.112 ***	-0.052 **	-0.084 ***	-0.064 ***	-0.157 ***	-0.157 ***	0.006	0.041 ***
		(0.035)	(0.020)	(0.022)	(0.023)	(0.016)	(0.018)	(0.018)	(0.015)	(0.015)
flash	-0.081	0.007	0.031 **	0.063 ***	0.042 ***	-0.064 ***	-0.049 ***	-0.049 ***	0.075 ***	-0.007
	(0.012)	(0.013)	(0.012)	(0.013)	(0.013)	(0.011)	(0.013)	(0.013)	(0.012)	(0.013)
qr	0.002 ***	0.003	0.045 ***	0.047 ***	-0.101 ***	-0.116 ***	-0.032 *	-0.032 *	-0.215 ***	-0.013
	(0.010)	(0.012)	(0.014)	(0.018)	(0.018)	(0.015)	(0.017)	(0.017)	(0.016)	(0.019)
felica	0.196 ***	0.116 ***	0.011	-0.038 ***	0.043 ***	0.100 ***	0.023 *	0.023 *	0.029 ***	0.094 ***
	(0.017)	(0.013)	(0.012)	(0.011)	(0.010)	(0.010)	(0.012)	(0.012)	(0.010)	(0.012)
full-browser			0.220 ***	0.306 ***	0.075 ***	0.065 ***	0.000	0.000	0.008	0.034 ***
			(0.037)	(0.031)	(0.018)	(0.013)	(0.013)	(0.013)	(0.009)	(0.009)
suica				0.076 **	0.157 ***	0.080 ***	0.099 ***	0.099 ***	0.012	-0.020
				(0.038)	(0.018)	(0.014)	(0.015)	(0.015)	(0.012)	(0.014)
gps	-0.083 ***	-0.052 ***	-0.020	0.054 ***	0.107 ***	0.117 ***	0.093 ***	0.093 ***	0.018	0.076 ***
	(0.012)	(0.012)	(0.013)	(0.017)	(0.023)	(0.017)	(0.017)	(0.017)	(0.015)	(0.014)
decomail		-0.003	0.084 ***	0.024 *	-0.085 ***	-0.072 ***	0.090 ***	0.090 ***	0.066 ***	0.083 ***
		(0.054)	(0.016)	(0.014)	(0.015)	(0.020)	(0.025)	(0.025)	(0.017)	(0.014)
movie	0.115 ***	0.258 ***	0.255 ***	0.137 ***	0.003	0.099 ***	0.283 ***	0.283 ***	-0.379 ***	-0.296 ***
	(0.023)	(0.095)	(0.028)	(0.031)	(0.035)	(0.033)	(0.041)	(0.041)	(0.032)	(0.028)
music	-0.014	0.003	0.049 ***	0.100 ***	0.003	0.006	0.064 ***	0.064 ***	0.036 ***	0.005
	(0.013)	(0.013)	(0.012)	(0.012)	(0.011)	(0.008)	(0.008)	(0.008)	(0.007)	(0.008)
radio	0.072 ***	0.170 ***	0.165 ***	0.163 ***	0.084 ***	0.028 **	0.022 *	0.022 *	0.073 ***	0.042 ***
	(0.019)	(0.020)	(0.015)	(0.015)	(0.013)	(0.011)	(0.012)	(0.012)	(0.010)	(0.010)
tv	-0.047 ***	0.015	0.103 ***	0.221 ***	0.171 ***	0.089 ***	-0.118 ***	-0.118 ***	0.310 ***	0.217 ***
	(0.015)	(0.017)	(0.018)	(0.023)	(0.026)	(0.026)	(0.032)	(0.032)	(0.022)	(0.019)
age	-0.078 ***	-0.065 ***	-0.046 ***	-0.046 ***	-0.055 ***	-0.065 ***	-0.076 ***	-0.076 ***	-0.082 ***	-0.057 ***
	(0.003)	(0.003)	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)
location	0.008 *	0.003	-0.002	-0.011 *	-0.013 **	-0.011 **	-0.018 ***	-0.018 ***	0.002	-0.011 **
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.004)	(0.005)
time dummy	-0.040 ***	-0.037 ***	0.008 ***	-0.041 ***	-0.048 ***	-0.040 ***	-0.057 ***	-0.057 ***	-0.002	-0.033 ***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.005)	(0.005)	(0.006)	(0.006)	(0.004)	(0.005)
constant	7.305 ***	7.879 ***	7.955 ***	8.455 ***	6.303 ***	5.555 ***	3.669 ***	3.669 ***	5.964 ***	6.749 ***
	(0.181)	(0.199)	(0.214)	(0.277)	(0.314)	(0.336)	(0.405)	(0.405)	(0.260)	(0.254)
N	2246	2324	2245	2168	2293	2423	2480	2480	3392	3324
R^2	0.718	0.648	0.629	0.646	0.679	0.682	0.596	0.596	0.640	0.545

NOTE: Robust standard errors are in parentheses. $*\ p < .1$. $**\ p < .05$. $***\ p < .01$.

Table 6: Regression Results: NTT DoCoMo (2002Q1-2004Q2)

variable	2002 Q1 2002 Q2	2002 Q2 2002 Q3	2002 Q3 2002 Q4	2002 Q4 2003 Q1	2003 Q1 2003 Q2	2003 Q2 2003 Q3	2003 Q3 2003 Q4	2003 Q4 2004 Q1	2004 Q1 2004 Q2
log(speed)			0.115 ***	-0.050 *	-0.211 ***	0.021 **	0.002	-0.048	0.189 ***
			(0.025)	(0.028)	(0.067)	(0.010)	(0.023)	(0.029)	(0.012)
log(camera)			-0.005	-0.028	-0.029	0.020	0.059 ***	0.012	0.052 ***
			(0.033)	(0.019)	(0.025)	(0.019)	(0.012)	(0.014)	(0.017)
log(screen)			0.204 ***	0.163 ***	0.239 **	0.110 *	-0.022	-0.077 ***	-0.013
			(0.064)	(0.040)	(0.103)	(0.063)	(0.023)	(0.025)	(0.028)
log(duration)				0.244	0.672 **	0.677 ***	0.775 ***	0.768 ***	-0.353 ***
				(0.176)	(0.278)	(0.159)	(0.143)	(0.241)	(0.126)
ringtone	-0.025 ***	-0.030 ***	-0.002	-0.019 ***	-0.032 ***	0.000	-0.001 *	-0.001	-0.001 *
	(0.003)	(0.003)	(0.004)	(0.006)	(0.010)	(0.001)	(0.001)	(0.001)	(0.001)
g3							0.069	0.317 ***	
							(0.057)	(0.074)	
java				0.276 ***	0.474 ***	0.248 ***	0.348 ***	0.450 ***	0.126 ***
				(0.038)	(0.065)	(0.019)	(0.031)	(0.038)	(0.036)
truetone								0.053	-0.084 ***
								(0.041)	(0.031)
truetone-full									
flash					0.287 ***	-0.104	-0.133 ***	-0.180 ***	
					(0.109)	(0.072)	(0.035)	(0.044)	
qr					0.492 **	-0.008	-0.019	0.127 ***	0.117 ***
					(0.232)	(0.042)	(0.019)	(0.019)	(0.020)
felica									
full-browser									
suica									
gps							0.085	0.085 ***	0.027
							(0.070)	(0.029)	(0.019)
decomail									
movie	-0.025		0.041	0.059	0.532 ***				
	(0.033)		(0.095)	(0.093)	(0.180)				
music									
radio									
tv				0.236 ***	0.342 ***	0.041 *	-0.046 **	-0.130 ***	-0.175 ***
				(0.057)	(0.078)	(0.022)	(0.018)	(0.020)	(0.018)
age	-0.023	-0.100 ***	-0.121 ***	-0.136 ***	-0.123 ***	-0.115 ***	-0.147 ***	-0.141 ***	-0.114 ***
	(0.020)	(0.025)	(0.020)	(0.012)	(0.011)	(0.008)	(0.008)	(0.007)	(0.005)
location	-0.002	0.028	0.005	-0.007	0.013	0.008	-0.005	-0.003	0.009
	(0.011)	(0.018)	(0.013)	(0.010)	(0.010)	(0.008)	(0.007)	(0.008)	(0.006)
time dummy	-0.013	-0.025	-0.105 ***	0.025 **	-0.088 ***	-0.088 ***	0.035 ***	0.035 ***	-0.014 *
	(0.019)	(0.031)	(0.023)	(0.012)	(0.012)	(0.010)	(0.010)	(0.010)	(0.007)
constant	8.548 ***	8.717 ***	5.499 ***	5.060 ***	3.703 **	3.000 **	3.860 ***	4.539 ***	8.547 ***
	(0.062)	(0.086)	(0.637)	(0.736)	(1.727)	(1.185)	(0.695)	(1.119)	(0.591)
N	65	115	218	344	422	571	729	762	856
$\bar{R}^2$	0.861	0.828	0.751	0.667	0.720	0.812	0.757	0.742	0.844

NOTE: Robust standard errors are in parentheses. $* \, p < .1$. $** \, p < .05$. $*** \, p < .01$.

Table 7: Regression Results: NTT DoCoMo (2004Q2-2006Q4)

variable	2004 Q2 2004 Q3	2004 Q3 2004 Q4	2004 Q4 2005 Q1	2005 Q1 2005 Q2	2005 Q2 2005 Q3	2005 Q3 2005 Q4	2005 Q4 2006 Q1	2006 Q1 2006 Q2	2006 Q2 2006 Q3	2006 Q3 2006 Q4
log(speed)	0.087 ***	0.219 ***	0.127 ***	0.260 ***	0.331 ***	0.350 ***	0.442 ***	0.254 ***	-0.014	-0.005
	(0.021)	(0.019)	(0.020)	(0.028)	(0.020)	(0.022)	(0.028)	(0.023)	(0.015)	(0.010)
log(camera)	0.135 ***	0.080 ***	0.080 ***	0.219 ***	0.240 ***	0.235 ***	0.088 ***	0.004	0.010	0.016
	(0.016)	(0.025)	(0.020)	(0.021)	(0.018)	(0.021)	(0.019)	(0.014)	(0.011)	(0.011)
log(screen)	0.138 ***	0.193 ***	0.094 ***	-0.285 ***	-0.143 ***	-0.106 *	0.157 *	0.881 ***	0.589 ***	0.070
	(0.026)	(0.038)	(0.036)	(0.043)	(0.026)	(0.056)	(0.088)	(0.064)	(0.081)	(0.091)
log(duration)	-0.564 ***	-0.504 ***	-0.151 **	0.060	0.257 ***	0.179 **	0.402 ***	0.286 ***	0.399 ***	0.355 ***
	(0.067)	(0.067)	(0.068)	(0.088)	(0.081)	(0.073)	(0.084)	(0.056)	(0.047)	(0.046)
ringtone	0.002 ***	0.008 ***	0.002 *	-0.004 ***	-0.002 ***	-0.003 ***	0.000	0.001 ***	0.000 *	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
g3			-0.124 ***	-0.089 **	-0.219 ***	-0.262 ***	-0.824 ***	-0.705 ***		0.431 ***
			(0.033)	(0.041)	(0.037)	(0.089)	(0.132)	(0.035)		(0.088)
java	0.294 ***	-0.038	0.353 ***	0.085 **	-0.070 **	0.027	-0.212 **		0.066	
	(0.047)	(0.051)	(0.048)	(0.043)	(0.036)	(0.068)	(0.103)		(0.079)	
truetone	0.259 ***	0.349 ***	0.130 ***	-0.310 ***	-0.243 ***	-0.186 ***	-0.290 ***	0.248 ***		
	(0.052)	(0.052)	(0.042)	(0.051)	(0.036)	(0.035)	(0.040)	(0.046)		
truetone-full								0.084 ***	0.128 ***	0.105 ***
								(0.030)	(0.016)	(0.015)
flash	-0.414 ***		-0.402 ***		-0.094 **	-0.244 ***	-0.112 ***	0.166 ***	0.074 **	0.007
	(0.065)		(0.060)		(0.045)	(0.041)	(0.035)	(0.035)	(0.033)	(0.036)
qr	-0.053 **	-0.133 ***	-0.006					-0.188 ***	-0.105 ***	-0.048
	(0.021)	(0.047)	(0.051)					(0.036)	(0.032)	(0.035)
felica	0.066 ***	0.027 **	-0.046 ***	-0.035 ***	0.052 ***	0.099 ***	0.099 ***	0.130 ***	0.133 ***	0.122 ***
	(0.015)	(0.012)	(0.009)	(0.010)	(0.009)	(0.010)	(0.015)	(0.013)	(0.013)	(0.016)
full-browser				0.150 *	0.119 ***	0.136 ***	0.013	-0.082 ***	-0.020 **	0.047 ***
				(0.078)	(0.028)	(0.023)	(0.022)	(0.014)	(0.010)	(0.010)
suica				0.004	0.085 ***	0.007	0.052 ***	0.067 ***	0.021 *	0.010
				(0.034)	(0.018)	(0.017)	(0.015)	(0.011)	(0.012)	(0.016)
gps	-0.071 ***	-0.123 ***	-0.079 ***	0.032						
	(0.016)	(0.019)	(0.021)	(0.045)						
decomail		-0.006	-0.002	-0.080 ***	-0.176 ***	-0.281 ***	0.029	-0.198 ***	-0.271 ***	-0.205 ***
		(0.040)	(0.014)	(0.018)	(0.017)	(0.066)	(0.104)	(0.016)	(0.075)	(0.015)
movie										-0.254 ***
										(0.086)
music	0.114 ***	0.118 ***	0.208 ***	0.167 ***	0.071 ***	0.098 ***	0.098 ***	0.119 ***	0.076 ***	0.028 ***
	(0.028)	(0.025)	(0.021)	(0.021)	(0.016)	(0.014)	(0.014)	(0.009)	(0.009)	(0.011)
radio							-0.020	0.041 **	0.143 ***	0.119 ***
							(0.029)	(0.019)	(0.021)	(0.026)
tv	-0.188 ***	-0.618 ***		0.115					0.275 ***	
	(0.018)	(0.062)		(0.097)					(0.083)	
age	-0.105 ***	-0.090 ***	-0.075 ***	-0.081 ***	-0.078 ***	-0.081 ***	-0.098 ***	-0.104 ***	-0.107 ***	-0.085 ***
	(0.004)	(0.004)	(0.004)	(0.005)	(0.004)	(0.004)	(0.004)	(0.003)	(0.002)	(0.003)
location	0.016 ***	0.011 *	0.004	-0.010	-0.009	0.002	0.001	0.002	0.001	-0.025 ***
	(0.005)	(0.006)	(0.005)	(0.006)	(0.005)	(0.006)	(0.006)	(0.005)	(0.004)	(0.005)
time dummy	0.006	-0.021 ***	0.012 *	-0.001	-0.047 ***	-0.062 ***	0.031 ***	0.011 **	-0.014 ***	0.004
	(0.006)	(0.006)	(0.006)	(0.007)	(0.006)	(0.006)	(0.007)	(0.005)	(0.005)	(0.005)
constant	8.035 ***	6.646 ***	6.397 ***	8.590 ***	5.950 ***	5.990 ***	2.213 *	-4.664 ***	-1.038	5.061 ***
	(0.356)	(0.479)	(0.495)	(0.686)	(0.486)	(0.761)	(1.181)	(0.929)	(1.054)	(1.091)
N	1020	996	970	1039	1149	1139	1070	1329	1598	1572
R^2	0.893	0.855	0.866	0.835	0.860	0.829	0.782	0.850	0.824	0.786

NOTE: Robust standard errors are in parentheses. $* \ p < .1$. $** \ p < .05$. $*** \ p < .01$.

Table 8: Regression Results: au by KDDI (2002Q1-2004Q2)

variable	2002 Q1 2002 Q2	2002 Q2 2002 Q3	2002 Q3 2002 Q4	2002 Q4 2003 Q1	2003 Q1 2003 Q2	2003 Q2 2003 Q3	2003 Q3 2003 Q4	2003 Q4 2004 Q1	2004 Q1 2004 Q2
log(speed)	-0.019 ***	0.064 ***	0.032 ***	0.021	-0.008	-0.012	0.213 ***	0.206 ***	0.066 ***
	(0.007)	(0.013)	(0.004)	(0.017)	(0.010)	(0.011)	(0.026)	(0.017)	(0.012)
log(camera)			0.082 ***	0.177 ***	0.061 ***	0.049 **	0.142 ***	0.086 ***	0.049
			(0.026)	(0.024)	(0.020)	(0.023)	(0.024)	(0.024)	(0.050)
log(screen)	0.185 ***	0.064				0.072 ***	0.033 **	0.060 ***	0.217 ***
	(0.043)	(0.073)				(0.020)	(0.015)	(0.017)	(0.020)
log(duration)	-0.272 ***	0.136 *				0.770 **	-1.672 ***	-1.693 ***	0.015
	(0.055)	(0.073)				(0.346)	(0.253)	(0.185)	(0.140)
ringtone	0.000	0.003 ***					0.004 ***	0.006 ***	0.000
	(0.001)	(0.001)					(0.001)	(0.001)	(0.002)
g3	-0.045 **	-0.117 ***							
	(0.018)	(0.015)							
java	-0.094 ***	-0.053 ***		0.018	0.068 ***	-0.108 ***	-0.038	-0.104 ***	0.026
	(0.020)	(0.022)		(0.040)	(0.022)	(0.029)	(0.024)	(0.031)	(0.069)
truetone				-0.037 *	0.004	-0.050	0.165 ***		
				(0.022)	(0.020)	(0.034)	(0.037)		
truetone-full									
flash									
qr								-0.057 **	0.065 ***
								(0.029)	(0.025)
felica									
full-browser									
suica									
gps	0.194 ***					0.137 ***	0.161 ***	0.198 ***	0.020
	(0.020)					(0.020)	(0.020)	(0.029)	(0.073)
decomail									
movie	0.028	0.006	0.053 **	0.014	0.096 ***	0.039 *	0.077 **		
	(0.019)	(0.025)	(0.021)	(0.029)	(0.035)	(0.023)	(0.031)		
music									
radio							0.276 ***	0.245 ***	-0.243 ***
							(0.058)	(0.042)	(0.031)
tv									
age	-0.044 ***	-0.060 ***	-0.055 ***	-0.069 ***	-0.064 ***	-0.052 ***	-0.032 ***	-0.033 ***	-0.018 ***
	(0.007)	(0.009)	(0.010)	(0.011)	(0.010)	(0.008)	(0.007)	(0.007)	(0.006)
location	0.005	0.008 *	0.001	0.003	0.006	0.004	0.009	0.009	0.006
	(0.004)	(0.004)	(0.005)	(0.006)	(0.007)	(0.006)	(0.007)	(0.007)	(0.008)
time dummy	-0.044 ***	0.013	0.012	-0.107 ***	-0.046 ***	-0.034 ***	-0.055 ***	-0.011	-0.039 ***
	(0.009)	(0.010)	(0.008)	(0.012)	(0.011)	(0.009)	(0.009)	(0.009)	(0.009)
constant	7.186 ***	6.163 ***	7.359 ***	7.168 ***	7.493 ***	2.930	13.586 ***	13.876 ***	4.697 ***
	(0.680)	(0.532)	(0.064)	(0.073)	(0.065)	(1.822)	(1.153)	(0.870)	(0.587)
N	372	368	131	241	285	368	483	485	534
$\bar{R}^2$	0.873	0.642	0.886	0.839	0.728	0.701	0.669	0.765	0.708

NOTE: Robust standard errors are in parentheses. $*\ p < .1$. $**\ p < .05$. $***\ p < .01$.

Table 9: Regression Results: au by KDDI (2004Q2-2006Q4)

variable	2004 Q2 2004 Q3	2004 Q3 2004 Q4	2004 Q4 2005 Q1	2005 Q1 2005 Q2	2005 Q2 2005 Q3	2005 Q3 2005 Q4	2005 Q4 2006 Q1	2006 Q1 2006 Q2	2006 Q2 2006 Q3	2006 Q3 2006 Q4
log(speed)	0.062 ***	-0.014	-0.075 ***	-0.161 ***	0.069 *	-0.162 ***	-0.086 ***	-0.021 ***	0.027 ***	0.077 ***
	(0.017)	(0.015)	(0.012)	(0.012)	(0.042)	(0.032)	(0.029)	(0.006)	(0.007)	(0.012)
log(camera)	0.183 ***	0.204 ***	0.176 ***	0.244 ***	-0.098	0.431 ***	0.183 ***	0.171 ***	0.168 ***	0.139 ***
	(0.027)	(0.022)	(0.018)	(0.019)	(0.075)	(0.029)	(0.019)	(0.018)	(0.016)	(0.020)
log(screen)	0.382 ***	0.161 ***	-0.163 ***	-0.277 ***	0.481 **	-0.240 *	0.137	0.568 ***	1.097 ***	0.413 ***
	(0.021)	(0.045)	(0.033)	(0.042)	(0.213)	(0.136)	(0.121)	(0.108)	(0.094)	(0.091)
log(duration)	0.703 ***	1.731 ***	2.410 ***	3.135 ***	1.001 ***	-0.389 ***	-0.125	-0.590 ***	-1.343 ***	-0.799 ***
	(0.144)	(0.146)	(0.138)	(0.130)	(0.148)	(0.115)	(0.103)	(0.104)	(0.105)	(0.135)
ringtone	-0.014 ***	-0.015 ***	-0.012 ***	-0.019 ***	0.007 ***	-0.020 ***	0.004 ***	0.003 ***	0.001 ***	-0.002 ***
	(0.001)	(0.001)	(0.001)	(0.002)	(0.003)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)
g3										
java	-0.058	-0.012	-0.017	-0.192 ***	-1.207 ***					
	(0.043)	(0.029)	(0.031)	(0.045)	(0.292)					
truetone										
truetone-full		-0.221 ***	-0.301 ***	-0.410 ***	-0.568 ***	0.686 ***	0.161 *			
		(0.048)	(0.029)	(0.028)	(0.112)	(0.093)	(0.089)			
flash	-0.067	0.026	0.069 **	0.147 ***	0.150 ***	0.040	0.053		0.434 ***	0.216 ***
	(0.062)	(0.054)	(0.033)	(0.028)	(0.034)	(0.026)	(0.039)		(0.078)	(0.066)
qr	0.191 ***	0.112 ***	0.078 ***	0.077 ***	-0.503 ***	-0.053		-0.078 *		
	(0.016)	(0.019)	(0.023)	(0.027)	(0.150)	(0.080)		(0.046)		
felica					-0.423 ***	1.196 ***	-0.103 **		-0.450 ***	-0.174 ***
					(0.156)	(0.094)	(0.041)		(0.025)	(0.023)
full-browser			0.307 ***	0.489 ***	0.387 ***	-0.292 ***	0.088 ***	0.044 **	0.049 ***	0.140 ***
			(0.038)	(0.032)	(0.051)	(0.041)	(0.023)	(0.018)	(0.016)	(0.022)
suica								-0.342 ***		
								(0.029)		
gps	-0.047	-0.027	0.040 *	0.177 ***	0.518 ***	-0.427 ***	-0.171 **			
	(0.036)	(0.022)	(0.022)	(0.024)	(0.138)	(0.066)	(0.075)			
decomail									0.293 ***	0.306 ***
									(0.048)	(0.028)
movie										
music			-0.025	0.058 **	0.093 ***	-0.340 ***	0.017	-0.090 ***	-0.157 ***	-0.225 ***
			(0.046)	(0.023)	(0.032)	(0.037)	(0.018)	(0.016)	(0.017)	(0.026)
radio	-0.539 ***	-0.513 ***	-0.249 ***	-0.218 ***	0.348 ***	-0.230 ***	0.065 ***	0.231 ***	0.201 ***	0.108 ***
	(0.036)	(0.044)	(0.029)	(0.025)	(0.098)	(0.034)	(0.022)	(0.017)	(0.014)	(0.014)
tv										
age	-0.038 ***	-0.044 ***	-0.037 ***	-0.063 ***	-0.043 ***	-0.036 ***	-0.046 ***	-0.082 ***	-0.049 ***	-0.038 ***
	(0.005)	(0.007)	(0.008)	(0.007)	(0.009)	(0.007)	(0.008)	(0.007)	(0.006)	(0.006)
location	0.005	-0.005	-0.010	-0.004	0.001	0.005	-0.001	-0.009	-0.008	-0.019 **
	(0.008)	(0.008)	(0.009)	(0.008)	(0.010)	(0.008)	(0.008)	(0.007)	(0.008)	(0.008)
time dummy	-0.122 ***	-0.036 ***	-0.067 ***	-0.052 ***	-0.070 ***	-0.069 ***	-0.115 ***	-0.003	-0.046 ***	0.022 **
	(0.009)	(0.009)	(0.011)	(0.010)	(0.012)	(0.009)	(0.011)	(0.009)	(0.009)	(0.009)
constant	-0.552	-2.991 ***	-2.650 ***	-3.989 ***	-2.227	12.737 ***	6.120 ***	3.325 **	1.038	6.069 ***
	(0.615)	(0.522)	(0.565)	(0.570)	(2.448)	(1.820)	(1.567)	(1.346)	(1.146)	(1.055)
N	695	751	741	666	699	762	801	950	1012	994
$\bar{R}^2$	0.658	0.595	0.538	0.648	0.481	0.628	0.574	0.635	0.558	0.462

NOTE: Robust standard errors are in parentheses. $*\ p < .1$. $**\ p < .05$. $***\ p < .01$.

Table 10: Regression Results: Vodafone/SoftBank (2002Q1-2004Q2)

variable	2002 Q1 2002 Q2	2002 Q2 2002 Q3	2002 Q3 2002 Q4	2002 Q4 2003 Q1	2003 Q1 2003 Q2	2003 Q2 2003 Q3	2003 Q3 2003 Q4	2003 Q4 2004 Q1	2004 Q1 2004 Q2
log(speed)	0.115 ***	0.123 ***	0.127 **	0.136 **	0.154 ***	0.231 ***	0.172 ***	0.222 ***	0.297 ***
	(0.030)	(0.027)	(0.060)	(0.066)	(0.031)	(0.024)	(0.027)	(0.035)	(0.083)
log(camera)	0.038 **	-0.067 ***	-0.218 *	-0.074 *	-0.124 ***	0.036 *	0.101 ***	0.008	-0.028
	(0.018)	(0.014)	(0.123)	(0.039)	(0.030)	(0.020)	(0.022)	(0.018)	(0.039)
log(screen)			-0.184	0.159 ***	0.116 ***	-0.054 **	-0.111 ***	-0.068 ***	0.080 ***
			(0.164)	(0.035)	(0.025)	(0.024)	(0.030)	(0.023)	(0.018)
log(duration)				0.357 **	0.647 *	1.472 ***	0.571 ***	0.279 *	0.056
				(0.165)	(0.346)	(0.182)	(0.136)	(0.148)	(0.240)
ringtone	0.004 **	0.001	0.005 ***	0.006 ***	0.001	-0.002	-0.005 ***	-0.007 ***	
	(0.002)	(0.001)	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	
g3								-0.338 **	
								(0.146)	
java	0.072 *	0.141 ***	0.050	-0.037	0.110 **	0.180 ***	0.105 ***	0.084 ***	0.061 ***
	(0.038)	(0.022)	(0.061)	(0.049)	(0.045)	(0.026)	(0.016)	(0.013)	(0.019)
truetone									
truetone-full									
flash									
qr			-0.115 ***	0.025	0.157 **	-0.254 ***	0.077 **	0.136 ***	0.120
			(0.022)	(0.029)	(0.071)	(0.027)	(0.032)	(0.028)	(0.084)
felica									
full-browser									
suica									
gps									
decomail									
movie									
music	-0.047 **	0.035	-0.025	0.098	0.146 ***		-0.032	-0.017	-0.084 **
	(0.024)	(0.021)	(0.063)	(0.072)	(0.044)		(0.029)	(0.024)	(0.037)
radio									
tv							-0.235 *		-0.728 ***
							(0.130)		(0.267)
age	-0.042 ***	-0.072 ***	-0.089 ***	-0.041 ***	-0.063 ***	-0.084 ***	-0.076 ***	-0.087 ***	-0.106 ***
	(0.007)	(0.005)	(0.007)	(0.010)	(0.012)	(0.007)	(0.006)	(0.006)	(0.006)
location	-0.001	0.000	0.000	0.004	0.036 ***	0.052 ***	0.025 ***	0.003	0.000
	(0.006)	(0.006)	(0.006)	(0.007)	(0.009)	(0.007)	(0.007)	(0.007)	(0.008)
time dummy	-0.006	-0.033 ***	-0.037 ***	-0.184 ***	-0.056 ***	-0.066 ***	-0.005	0.175 ***	-0.002
	(0.009)	(0.006)	(0.009)	(0.013)	(0.015)	(0.010)	(0.008)	(0.008)	(0.010)
constant	7.108 ***	7.460 ***	9.666 ***	4.082 ***	2.865	0.170	5.097 ***	6.370 ***	5.489 ***
	(0.063)	(0.061)	(1.222)	(1.064)	(1.802)	(0.960)	(0.871)	(0.905)	(1.369)
N	253	300	313	310	298	372	464	457	426
$\bar{R}^2$	0.912	0.903	0.867	0.840	0.741	0.786	0.798	0.882	0.828

NOTE: Robust standard errors are in parentheses. $* \ p < .1$. $** \ p < .05$. $*** \ p < .01$.

Table 11: Regression Results: Vodafone/SoftBank (2004Q2-2006Q4)

variable	2004 Q2 2004 Q3	2004 Q3 2004 Q4	2004 Q4 2005 Q1	2005 Q1 2005 Q2	2005 Q2 2005 Q3	2005 Q3 2005 Q4	2005 Q4 2006 Q1	2006 Q1 2006 Q2	2006 Q2 2006 Q3	2006 Q3 2006 Q4
log(speed)	-0.745 ***	0.068	0.131 ***	0.037 ***	-0.017 **	-0.036 ***	-0.023 ***	-0.284 ***	0.294 ***	-0.017
	(0.222)	(0.054)	(0.028)	(0.014)	(0.007)	(0.006)	(0.007)	(0.053)	(0.036)	(0.022)
log(camera)	0.551 ***	-0.060 **	-0.071 ***	0.339 ***	0.321 ***	0.321 ***	0.270 ***	0.200 ***	0.212 ***	0.141 ***
	(0.139)	(0.027)	(0.016)	(0.031)	(0.024)	(0.024)	(0.020)	(0.018)	(0.012)	(0.045)
log(screen)	0.040 **	-0.038 **	-0.012					0.350 ***	-0.260 ***	0.066
	(0.018)	(0.019)	(0.021)					(0.085)	(0.040)	(0.044)
log(duration)	0.622	-0.705 **	0.355 ***					1.646 ***	-1.104 ***	0.548 ***
	(0.464)	(0.277)	(0.113)					(0.337)	(0.213)	(0.147)
ringtone	0.008 ***	0.012 ***	0.002	0.008 ***	0.004 ***	-0.004 ***	0.000 **	0.001 ***	0.001 ***	0.000
	(0.001)	(0.003)	(0.002)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
g3		0.034	-0.038	0.286 ***	0.482 ***			0.505 ***	-0.575 ***	
		(0.153)	(0.070)	(0.041)	(0.068)			(0.090)	(0.062)	
java	0.058 **	0.031	0.010	0.703 ***					-0.116 ***	
	(0.023)	(0.021)	(0.021)	(0.053)					(0.025)	
truetone		-0.107		-0.311 ***	-0.050	-0.557 ***	-0.353 ***	0.234 **	-0.516 ***	-0.111
		(0.072)		(0.038)	(0.040)	(0.035)	(0.038)	(0.091)	(0.059)	(0.159)
truetone-full					-0.405 ***	0.061 *	0.093 ***	0.111 ***	-0.155 ***	-0.105 *
					(0.038)	(0.035)	(0.019)	(0.022)	(0.015)	(0.058)
flash			0.077	0.161 ***	0.151 ***	0.217 ***	0.107 ***	0.504 ***	-0.379 ***	0.086
			(0.066)	(0.038)	(0.023)	(0.019)	(0.025)	(0.091)	(0.063)	(0.057)
qr	-0.594 ***	0.094 **	-0.008	-1.104 ***	-0.414 ***	0.217 ***	0.071 ***	0.002	-0.084 ***	0.051
	(0.159)	(0.038)	(0.024)	(0.081)	(0.048)	(0.048)	(0.018)	(0.015)	(0.012)	(0.118)
felica						-0.128 ***	0.013	-0.050 ***	0.060 ***	0.088 ***
						(0.049)	(0.015)	(0.012)	(0.011)	(0.029)
full-browser										-0.013
										(0.034)
suica								-0.817 ***	0.656 ***	-0.124 *
								(0.172)	(0.097)	(0.069)
gps						0.098 ***	0.069 ***	-0.006	-0.082 ***	-0.037
						(0.036)	(0.018)	(0.016)	(0.011)	(0.042)
decomail										
movie			-0.191							
			(0.134)							
music	0.643 ***	-0.166 ***	-0.076 ***	-0.005	-0.012	0.033	-0.040 ***	-0.048 ***	-0.094 ***	-0.075 *
	(0.197)	(0.035)	(0.018)	(0.016)	(0.030)	(0.029)	(0.016)	(0.013)	(0.011)	(0.044)
radio	0.529 ***	0.037	0.276 ***	0.206 ***	0.043 ***	0.001	-0.038 ***	0.038 ***	0.332 ***	0.109 ***
	(0.191)	(0.110)	(0.022)	(0.015)	(0.010)	(0.010)	(0.013)	(0.014)	(0.020)	(0.033)
tv	3.331 ***									
	(0.894)									
age	-0.061 ***	-0.053 ***	-0.040 ***	-0.058 ***	-0.070 ***	-0.065 ***	-0.041 ***	-0.071 ***	-0.009 **	-0.059 ***
	(0.008)	(0.008)	(0.008)	(0.007)	(0.005)	(0.004)	(0.005)	(0.004)	(0.004)	(0.006)
location	0.001	0.000	-0.003	-0.020 ***	-0.039 ***	-0.057 ***	-0.075 ***	-0.039 ***	0.018 ***	0.028 ***
	(0.009)	(0.008)	(0.006)	(0.006)	(0.005)	(0.005)	(0.006)	(0.005)	(0.003)	(0.007)
time dummy	-0.081 ***	-0.087 ***	0.135 ***	-0.047 ***	0.031 ***	0.006	-0.210 ***	0.059 ***	-0.014 ***	-0.152 ***
	(0.012)	(0.010)	(0.010)	(0.008)	(0.007)	(0.006)	(0.007)	(0.006)	(0.004)	(0.009)
constant	4.999 **	11.084 ***	5.622 ***	5.760 ***	5.984 ***	6.975 ***	7.031 ***	-4.239 *	13.915 ***	3.645 ***
	(2.093)	(1.551)	(0.696)	(0.129)	(0.117)	(0.051)	(0.071)	(2.357)	(1.351)	(1.056)
N	531	577	534	463	445	522	609	745	782	758
R^2	0.732	0.657	0.852	0.822	0.741	0.799	0.847	0.825	0.903	0.695

NOTE: Robust standard errors are in parentheses. $*\ p < .1$. $**\ p < .05$. $***\ p < .01$.