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An Analysis of Non-Hardware Characteristics of Laptop Computers by using Hedonic Price Model

Dong Yup Lee and Gi Hong Kim
Pusan National University, Pusan Korea E-mail: gkim@pusan.ac.kr

Abstract

The main purpose of this study is to analyze whether or not prices of laptop computers reflect their varying degrees of non-hardware characteristics such as the number of after-sale service center and the inclusion of OS software. For this purpose, we have employed Hedonic Price Model by which the interactions among hardware and non-hardware components could be analyzed. As a result, we have found that the number of after-sales service center and the inclusion of OS have a tendency to increase the prices of the laptop computers. This result is consistent with the following hypothesis: the more the number of after-sales service center is, the higher consumers are willing to pay for the laptop computers, when all other things being equal or held constant. The same conclusion can be applied to the case of the inclusion of OS; consumers are willing to pay more with the inclusion of OS. We have also found that after-sale service provided by laptop computer manufactures is not free, so that manufactures have a motivation to provide more after-sale service centers to get more profit.

Keywords*: Hedonics Price Analysis, Laptop, After-sale Service, Operating System, GLS*

1. Introduction

Hedonic pricing model is based on the following assumption that the value of goods is determined by the characteristics of the goods. For example, Rosen (1974) [1] suggested a model of product differentiation where goods are valued for their utility-bearing attributes or characteristics. In this sense, to purchase heterogeneous goods means to purchase a bundle of attributes inherent in these goods. Thus, their prices are determined by not only the quantities but also prices of the characteristics inherent in these goods.[2] Prices of these characteristics, accordingly, are named as hedonic prices or implicit prices. Court (1939) is the first scholar to name these prices of characteristics as hedonic prices (hedonic pricing). Court would like to measure the consumer pleasure (enjoyment) which can be obtained from the attributes of the cars (speed, internal comfort, stability, etc.). As is well known, hedonic prices (implicit prices) are not easily observed because the inherent characteristics of goods are

*The graduate school, College of Economics and International Trade, Department of Economics, Pusan National University, Pusan Korea, E-mail: yupkun@gmail.com

**Corresponding author, Professor, College of Economics and International Trade, Department of Economics, Pusan National University, Pusan Korea, E-mail: gkim@pusan.ac.kr

1 Rosen, S (1974), "Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition", *Journal of Political Economy*, 82(1), pp.34-55.

2 Triplett, Jack E.(1987), "Hedonic functions and hedonic indexes", in J. Eatwell, M. Milgate and P. Newman ed., *The New Palgrave : A Dictionary of Economics*, pp. 630-634

not sold separately but sold as a whole when goods are sold. Unlike the price of goods which is explicit, the prices of characteristics inherent in these goods only can be determined by estimation. It would be another reason why we call them implicit prices.

For this reason, we would like to employ regression analysis in order to estimate the prices of characteristics. Rosen (1974) said that under a fully competitive market, there exists a balance in implicit market of heterogeneous goods. In other words, the price of this attribute (obtained by regression), in a fully competitive market, is the same as the equilibrium price. Furthermore, he said that the form of hedonic function is not affected by the consumer's choices on their characteristics. Based on these theoretical explanations suggested by Rosen (1974), we can estimate the equilibrium price of the characteristics.

In this paper, we would like to estimate how much consumers are willing to pay for the value of each characteristic when buying laptop computers. This paper is organized as follows: First, in Section II the model based on Hedonic Price Model will be discussed. And the functional form of the model for the estimation of hedonic price will be introduced. In Section III, we will estimate the value of non-hardware characteristics with the optimal functional form. And the last chapter will be devoted to the conclusion.

2. The Model

In this section, we would like to suggest the practical estimation equation based on the Hedonic Price Model in order to analyze how much money consumers are willing to pay for the value of characteristics inherent in laptop computers. First of all, the general form of Hedonic function can be represented by the following equation (1):

$$P = h(S, N, L) \tag{1}$$

In this equation, dependent variable P represents price of laptop, S, N, L individual characteristics, and h the form of the regression expression functions. As is well known, there are lots of characteristics that cause price differentiation in laptop computers. We would like to classify them into hardware characteristics such as speed of CPU, size of monitor and capacity of hard-disk, and non-hardware characteristics such as the number of after-sale service(hereinafter A/S) and the inclusion of operating system (hereinafter OS). In this paper, we will discuss the importance of both hardware and non-hardware features simultaneously in explaining consumers' behavior in purchasing laptop computers.

However, we will give more attention to non-hardware features, particularly to A/S and OS; it would be our main contribution. The reasons are as follows. First of all, the effect of non-hardware components is not fully analyzed mainly because of the difficulty of getting relevant data, which is also deeply rooted in the characteristics of 'non-hardware'. For example, non-hardware features such as A/S cannot be observed when consumers decide to purchase laptops. Thus, consumers depend on media and reports of consumer group to get the relevant information, but that kind of method is not easy at all. Second, manufactures may be confronted with a question as following; in which area they must focus to increase both the whole sale and the profit, particularly between investing to R&D and A/S improvement. If manufactures are able to identify the importance of each component from hardware and non-hardware sources, they will easily determine whether invest to R&D (related with hardware sources) or A/S improvement (related with non-hardware sources) in launching new models in the market. For these reasons, we have estimated consumers' willingness to pay for A/S and OS using dummy variables in this paper.

As is explained in the previous section, many empirical analyses based on Hedonic Pricing model have been made since the introduction of the famous paper written by Rosen (1974). The functions used mainly to estimate the value were linear functions, quadratic functions, log-log function, semi-log function and exponential functions. Recently, a quadratic Box-Cox transformation function has been used to determine the functional form. Thus, until at this time, there is no standard functional form in Hedonic pricing model. For this reason, we would like to use log-log functions based on the recommendation by Dipasquale and Wheaton(1996); double-log functions is more realistic than linear functions because double-log functions reflect the law of diminishing returns.[3] In a log-log function estimation, the coefficient of each variable reflects the elasticity of the each characteristics. However, there are difficulties in processing and making interpretations of dummy variable in double-log model, since dummy variable has either 0 or 1 value and has not been changed into natural logarithm because log 0 is not defined. So, we will not use natural logarithm in dummy variables. In this case, the estimation coefficient of dummy variable does not represent its elasticity.

Table 1 Description of variables

Variable	Description	Expected Effect
LOG(PRICE)	**Log of price(Korea won)**	**N/A**
LOG(PROC)	**Log of processor performance index(cine bench r10)**	**+**
LOG(GPROC)	**Log of GPU performance index(3d mark 06)**	**+**
LOG(RAM)	**Log of random access memory(gigabyte)**	**+**
LOG(HDSIZE)	**Log of hard disk size(gigabyte)**	**+**
LOG(PIX)	**Log of number of pixels in maximum resolution**	**+**
LOG(AS)	**Log of number of A/S center**	**+**
LOG(WEIGHT)	**Log of weight(100g)**	**-**
LOG(DIAG)	**Log of diagonal measure of screen size(inches)**	**?**
DSSD	**Dummy variable for SSD**	**+**
DOS	**Dummy variable for OS**	**+**
DSANDY	**Dummy variable for Sandy bridge process**	**+**
DI5	**Dummy variable for I5**	**+**
DI7	**Dummy variable for I7**	**+**

Notes: SSD (Solid-State-Disk, make speed of hard disk faster by using flash memory), GPU (Graphics Processing Unit)

Hedonic pricing model used in the estimation can be expressed as:

$$log(PRICE) = \beta_1 + \beta_2 log(PROC) + \beta_3 log(GPROC) + \beta_4 log(RAM) + \beta_5 log(HDSIZE) + \beta_6 log(PIX) + \beta_7 log(AS) + \beta_8 log(WEIGHT) + \beta_9 log(DIAG) + \beta_{10} DSSD + \beta_{11} DOS + \beta_{12} SANDY + \beta_{13} I5 + \beta_{14} I7 + e \quad (2)$$

3 Dipasaquale and Wheaton(1996), pp. 67-72

Description of variables used in the equation (2) is suggested in the above <Table 1>. Explanatory variables (ROC), (GPROC), (RAM), (HDSIZE), and (PIX) are expected to give a (+) positive impact in laptop prices. Moreover, while variables such as (SSD) and (DSANDY), (DI5), (DI7), (DIAG) are expected to give a (+) positive impact in laptop prices, (WEIGHT) is expected to be a (-) negative impact factor. Except AS and DOS, which are non-hardware characteristics, all other variables represent hardware features.

3. Data and Empirical Results

In the above equations (2), the dependent variable represents the actual prices of laptops, and explanatory variables represent expected characteristics of laptop. As is discussed in the previous section, laptop characteristics include not only hardware characteristics but also non-hardware characteristics, all of which can be considered to the components of the consumer's utility function. In other words, both hardware characteristics such as CPU, monitor, hard disk size, and non- hardware characteristics such as A/S, OS will be taken into consideration in the utility function of purchasing a laptop.

The hardware characteristics as explanatory variables represent the performance of central processing unit (PROC), the performance of graphics processing units (GPROC), hard disk capacity (HDSIZE), the amount of memory (RAM), the monitor's size (DIAG), the monitor's resolution (PIX). The explanatory power of the variable of laptop's weight (WEIGHT) might be related with the following variables since hard disk of SSD (SSD), sandy bridge cpu process (DSANDY), i-5 cpu (DI5), and i-7 cpu (DI7) have weight and may increase the price of laptops.
Non-hardware features include A/S center number (AS), and a dummy variable of OS (DOS).[4] For our research purpose, the information of each laptop manufacturer's A/S level must be obtained, but as is mentioned before, it is very difficult to get that kind of information. The one of previous study[5] had relied on the method of survey to measure the level of A/S in each manufacturing companies. Because of the nature of the survey, there was some possibility for respondents to misunderstand the question about A/S level, to emphasize the reputation of manufactures rather than the actual level of A/S. Thus, that kind of research may have some tendency of bias. So, we have employed the method of investigating the total number of A/S centers of 8 manufacturers in Korea, rather than employing the method of survey. For the data regarding the inclusion of OS, we have visited the largest price comparison site (Dananwa) in Korea laptop market[6], and we can find the relevant data over 320 products (the number of sample). Moreover, we can find many relevant data, required for our regression, regarding dependent and explanatory variables in this site.

Table 2. The number of manufacturer's after-sales center

Samsung	LG	HP	DELL	Sony	Toshiba	MSI	ASUS
140	129	13	32	14	13	1	1

Note: Data taken from each company website.(2011.10)

According to <Table 2>, SAMSUNG shows the largest number of A/S, while MSI and ASUS show the least numbers. This fact means that domestic company has comparative advantage in

[4] One thing to note is that explanatory variables suggested in the equation (2) is not the entire characteristics that can be considered in pur chasing a laptop. Among them are HDMI, USB support, Bluetooth, etc. But, we think that the exclusion does not prohibit the relevance of our estimation results, particularly regarding non-hardware characteristics such as (AS) and (DOS).

[5] Shin Seung Sik, Kwak Seung Jun, Yoo Seung Hoon (2000), "Applying Hedonic Price Model to Analyzing Non-market Characteristic of Personal Computer," Journal of Technology Innovation 3, pp.85-101.

[6] The largest price comparison site in Korea laptop market. 2011

providing A/S centers than foreign companies. The descriptive statistics for the 320 samples are provided in the <Table 3>. According to this table, the average purchasing price of the 320 products is 976389.8 won. And the average of CPU (PROC) cine bench R10 rate is 8217.158 , which is slightly lower than the figure of Intel i5 2520M CPU (cine bench R10 rate: 8559). The average of GPU (GPROC) 3d mark rate is 5711.335, which is almost the same as the figure of g-force GT 520m GPU (3d mark rate: 5804). And the average capacity of Hard disk (HARD) is 590.918 GB (gigabyte) and the Memory (RAM) capacity, on the average, 4.318 GB (gigabyte). The size of the screen (DIAG), on the average, is 14.615 inches, while the average level of resolution (PIX) is 1,272,092 pixels. Weight (WEIGHT) of laptops, on the average, is 23.029 (100g), and the average rate of laptops which contains the product of SSD (DSSD) among all 320 products is 5.6 %. The percentage of laptops which are equipped with i5 CPU is 41.5% among 320 products. And i7 was 28.7%. Sandy Bridge processed CPU was on the average, 78.4%. Finally, the average number of A/S center was 43. From this perspective, we think that most manufacturers, except for SAMSUNG and LG, have A/S centers less than consumers expect. The result of estimation based on OLS is summarized in <Table 4>. According to this table, all the coefficients of variables except (WEIGHT) and (HDSIZE) have shown statistical significance, while they have not. The coefficient for (DIAG) has shown negative impacts, which is contrary to our expectation. Moreover, the coefficient for (WEIGHT) is non-significant though its negative impact is the same as our expectation. We initially expect that the coefficient for (HDSIZE) would be statistically insignificant, since the capacity of hard disk size will no longer affect its price due to reduction in production costs resulted from technological improvements. However, we have found that there is multi-collinearity problem between the variables (WEIGHT) and (DIAG). In order to solve this problem, we decided to exclude the variable of (WEIGHT) in the estimation. Moreover, to solve a heteroskedasicity problem which is common in cross section data, we will use the method of GLS(Generalized Least Square) in the estimation. The result of the GLS(Generalized Least Square) estimation is summarized in <Table 5>

Table 3. Descriptive Statistics for the Samples

	PRICE	PROC	GPROC	HDSIZE	RAM	DIAG	PIX	WEIGHT	DSSD	DOS	DI5	DI7	DSANDY	AS
Mean	976389.8	8217.158	5711.335	590.918	4.318	14.615	1272092.	23.029	0.056	0.762	0.415	0.287	0.784	43.234
Median	889000.0	7884.800	4831.200	506.000	4.000	15.600	1049088.	24.000	0.000	1.000	0.000	0.000	1.000	13.500
Maximum	4890000.	16809.50	20664.50	2000.000	16.000	17.300	2073600.	53.000	1.000	1.000	1.000	1.000	1.000	140.00
Minimum	246000.0	856.300	140.000	8.000	1.000	10.100	614000.0	3.430	0.000	0.000	0.000	0.000	0.000	1.000
Std. Dev.	519244.9	3573.144	3311.301	233.407	2.598	1.666	425132.0	6.454	0.230	0.426	0.493	0.453	0.411	54.007
Skewness	2.359	0.142	0.979	1.576	2.227	-0.765	1.043133	0.517	3.851	-1.233	0.342	0.939	-1.382	1.053
Kurtosis	14.207	2.651	4.666	9.485	10.007	3.535	2.785	4.621	15.837	2.522	1.117	1.881	2.912	2.246
Jarque-Bera	1971.584	2.699	88.242	693.309	919.439	35.085	58.644	49.35	2988.638	84.219	53.516	63.70	102.106	66.759
Probability	0.000	0.259	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sum	3.12E+08	2629491.	1827627.	189094.0	1382.000	4676.900	4.07E+08	7369.430	18.000	244.000	133.000	92.000	251.000	13835.00
Sum Sq. Dev.	8.60E+13	4.07E+09	3.50E+09	17378878	2153.488	886.3350	5.77E+13	13290.23	16.987	57.950	77.721	65.550	54.121	930337.4
Observations	320	320	320	320	320	320	320	320	320	320	320	320	320	320
Expected Effect		+	+	+	+	*?*	+	-	+	+	+	+	+	+

Table 4. Estimation result (Least Squares)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	**6.826**	0.616	11.072	0.0000
LOG(PROC)	**0.122*****	0.047	2.591	0.0100
LOG(GPROC)	**0.064*****	0.024	2.656	0.0083
LOG(RAM)	**0.162*****	0.033	4.826	0.0000
LOG(HDSIZE)	**0.029**	0.053	0.561	**0.5746**
LOG(PIX)	**0.431*****	0.045	9.422	0.0000
LOG(AS)	**0.025*****	0.006	3.856	0.0001
LOG(DIAG)	**-0.649*****	0.139	-4.654	0.0000
DSSD	**0.433*****	0.085	5.082	0.0000
DOS	**0.199*****	0.026	7.610	0.0000
DSANDY	**0.127*****	0.033	3.783	0.0002
DI5	**0.159*****	0.030	5.179	0.0000
DI7	**0.325*****	0.041	7.843	0.0000
R-squared	**0.876701**	**Adjusted R-squared**		**0.871881**
Durbin-Watson stat	**1.783988**	**J-statistic**		**2.60E-24**

Notes: The J-B corresponds to the test statistic for the null hypothesis of normality in sample returns distribution.
MacKinnon's (1991) 1% critical value is –3.435 for the ADF and PP tests.***and** indicate significance at the 1% and 5% and 10% levels, respectively.

All the coefficients are statistically significant except (HDSIZE), as is the same in OLS regression. This is due to the technical improvement in the capacity of the hard disk which affects laptop prices less than other variables. The sign of the explanatory variable (DIAG) is negative, which is consistent to our expectation. The increase of laptop weight caused by increasing the number of inches has a tendency to drop the price of the laptop. And, the sign of all other variables except (DIAG) is the same as our expectation. As is shown in <Table 5>, elasticity of (DSSD) is the highest one, 0.433, followed by resolution (PIX) 0.431, and a dummy variable (Di7) and (DOS) 0.325 and 0.199, respectively. However, while the other variables such as (PROC) or (GPROC), (RAM) show relatively low elasticity,[7] the variable of (AS) shows a relatively high elasticity compared to our expectation, 0.025. The value of coefficient of (AS) indicates two things. First, it is not a big factor to determine the purchase price of a laptop. Second, it shows that whenever there is 1% increase in the number of A/S center, customers are willing to pay 2.5% more for laptop. This result also shows that the inclusion of OS has an impact on prices of laptops in the same way of other explanatory variables.

7 PROC and GPROC and PIX is a quantitative variable. But SSD, I7, and OS is qualitative variable. Therefore, the elasticity for this variables is problematic to compare directly.

Table 5. Estimation result (Generalized Least Square)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	**6.688**	0.664	10.07	0.0000
LOG(PROC)	**0.120*****	0.049	2.448	0.0149
LOG(GPROC)	**0.067*****	0.025	2.684	0.0077
LOG(RAM)	**0.158*****	0.031	4.947	0.0000
LOG(HDSIZE)	**0.031**	0.035	0.907	**0.3647**
LOG(PIX)	**0.435*****	0.049	8.775	0.0000
LOG(AS)	**0.024*****	0.006	3.600	0.0004
LOG(WEIGHT)	**-0.047**	0.057	-0.825	**0.4097**
LOG(DIAG)	**-0.568*****	0.171	-3.315	0.0010
DSSD	**0.427*****	0.057	7.397	0.0000
DOS	**0.200*****	0.028	7.143	0.0000
DSANDY	**0.126*****	0.036	3.442	0.0007
DI5	**0.161*****	0.034	4.723	0.0000
DI7	**0.328*****	0.045	7.163	0.0000
R-squared	**0.876975**	**Adjusted R-squared**		**0.871748**
F-statistic	**167.7922**	**Durbin-Watson stat**		**1.791489**

Notes: The J-test statistic for the null hypothesis of normality in sample returns distribution. df12, 5% Chi-square critical value is 21.02 for J-test. ***and** indicate significance at the 1% and 5% and 10% levels, respectively.

4. Conclusions

In this paper, Hedonic Approach was used to measure the performance of laptop computers, particularly the effect of non-hardware characteristics. We are especially interested in the study based on the level of (AS) and the inclusion of operating system (OS). These interactions have gone unmeasured in previous work about laptop PC. For example, Paul Chwelos (2003) have used dummy variables to distinguish the development of OS from Dos to Windows in Microsoft, but found that none of these coefficients was significant at the 5% level. Thus, they concluded that there has been no significant performance interaction, either positive or negative, between laptop hardware and OS in the 1990s.

In this paper, we have found that such factors as the number AS center and the inclusion of OS affect on prices as well as other explanatory variables do. Moreover, the consumer's willingness to pay for a laptop actually relies on the monitor's resolution (PIX) and the inclusion of SSD, and the inclusion of OS, whose impacts seems to be greater than those of CPU and GPU, size of hard disk, capacity of RAM. Moreover, thanks to the effectiveness of AS and OS, we also suggest that, as for manufacturing companies, investment in A/S is as important as investment in R/D. Whenever there is 1% increase in the number of A/S centers, customers are willing to pay 0.024% more for laptop. However, there are a few drawbacks. Firstly, it is not easy to obtain data required for estimation model because of rapidly changing technology environment. Secondly, measuring of the level of A/S by finding the number of A/S may not be a proper method to

measure the level of A/S. All these drawbacks can be overcome by finding the proper method to find the relevant data, which is our future task.

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