Hedonic Analysis of Automobile Attributes in Korea*

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I. Introduction

The number of automobiles in Korea has been dramatically increasing since 1980s. About 13 million automobiles were registered as of January 2002, which is more than 13 times the number of 1985. Although the

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growth rate is recently declining, the number of automobiles tends to keep increasing with the varieties of designs and options to meet consumers preferences.

Traffic congestion and pollution are the side effects that are unavoidable under the current trend of increasing number of automobiles. In addition, as a net importer of oil from foreign countries, Korea faces extra burden of the increased amount of oil imports especially when oil prices rise. About 52 percent of total air pollution was, on the average, attributable to automobile movements in 2000 (Ministry of Environment, 2001). The monthly gasoline consumption increased from 1.98 million bbl in December 1991 to 5.20 million bbl in December 2000 (Korea Energy Economic Institute, 2001).

In order to reduce the traffic congestion and its related social costs, Korean government adopts two general policy measures: higher consumer price of gasoline; and higher efficiency of gasoline use. The increase in consumer price of gasoline, other than the price increase in World market, has been induced by taxation. There are several types of indirect taxes\textsuperscript{1} levied on consumer price of gasoline. As a result, the taxes comprise of about 70 percent of consumer price of gasoline in Korea. In order for consumers to select more fuel-efficient automobile, the Korean government required manufacturers to attach the fuel efficiency level sticker\textsuperscript{2} on every new automobile from 1989.

In this circumstance, the policy effects would be highly dependent upon the price elasticity of demand for gasoline and the consumers choice for

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\textsuperscript{1} The types of taxes include traffic tax, education tax, value added tax, and so forth.\textsuperscript{2} The fuel efficiency levels are graded by 5 degrees indicating (1) very high, (2) high, (3) average, (4) low, and (5) very low.
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fuel-efficient automobiles. There are very limited studies on the price elasticity of demand for gasoline in Korea. The estimated price elasticity of gasoline by Lee (1997) and Ryu (1997) was 0.227 and 0.35, respectively, using time-series data. However, few studies was previously conducted with regard to the fuel efficiency of the automobiles by using cross-section data except for Lee and Lee (2001). Their analysis was focused on the automobile market of 1997 in Korea. This study has some limitations in data regarding attributes and availability of automobiles compared to the recent market situations in Korea.

This paper intends to estimate the elasticities of fuel efficiency with respect to the price of gasoline. By using cross-section data, we expect that the estimated elasticities of fuel efficiency would provide us with the implication of the long-run own price elasticity of demand for gasoline in Korea.

II. Model

We apply the Atkinson and Halvorsen (1984) New Hedonic Technique model to Korean automobile market. The capital cost equation of automobile can be defined below with respect to the fuel efficiency and attributes of automobile:

\[ V = V(F, z) \]  \hspace{1cm} (1)

where \( V \) is the capital cost or price of an automobile, \( F \) is the fuel efficiency of the automobile, and \( z \) denotes the vector of its attributes.
The attributes may include styling, interior space, option availability, etc.

Since multicollinearity problem may appear when estimating the above equation (1), we could define the relationship between fuel efficiency and attributes by the following equation.

\[ F = F(z) \]  \hspace{1cm} (2)

Then, by substituting the equation (2) into equation (1), we obtain the reduced form of the capital cost function as follows.

\[ V = V(z) \]  \hspace{1cm} (3)

The equation (3) could provide the implicit prices of the attributes other than fuel efficiency by reflecting both their effects on fuel efficiency and their attraction values to consumers. A comparative static analysis can be used to examine the consumers choice between fuel efficiency and attributes under the assumption that decreasing some attributes of automobile can increase fuel efficiency. Utility maximization problem will be solved with a utility function along with the estimation of the equation (2) and (3).

The utility function is defined by \( H = H(z, G) \), where \( z \) is the vector of automobile attributes as seen in the above equations and \( G \) is the vector of all other goods. Assuming weak separability, we can write the utility function as \( H = H[U(z), G] \). Since \( U(z) \) is the subutility function of automobile, we can formulate a subutility maximization problem with the budget constraint. The budget in this case is represented by the automobile expenditure, which is given by.
\[ M = V(z) + \sum_{i=1}^{T} \frac{1}{(1 + r)^i} \frac{P_t D_t}{F(z)} \], where \( M \) is denotes the present value of the expenditures for the purchase and maintenance of the automobile, \( V(z) \) is the capital cost, \( r \) is the discount rate, \( T \) is the expected life time of the automobile, \( P_t \) is the expected real price of gasoline in the year \( t \), \( D_t \) is the driving mileage in year \( t \), and \( F(z) \) is the fuel efficiency (kilo meters per liter of gasoline).

The Lagrangean equation is given by

\[ L = U(z) + \lambda \left[ M - V(z) - \sum_{i=1}^{T} \frac{1}{(1 + r)^i} \frac{P_t D_t}{F(z)} \right] \tag{4} \]

By solving for the maximization of the Lagrangean equation and for the comparative–static analysis with respect to the change in the base year price of gasoline\(^3\) (denoted by \( P_0 \)), we could obtain the following equation.

\[ \frac{\partial F_i}{\partial P_0} = \sum_{i=1}^{n} \frac{\partial F_i}{\partial z_i} \cdot \frac{\partial z_i}{\partial P_0} \tag{5} \]

\( \frac{\partial F_i}{\partial z_i} \) in equation (5) can be obtained by using equation (2) while \( \frac{\partial z_i}{\partial P_0} \) can be given by solving a comparative–static analysis of the first-order conditions with respect to the base year price change of gasoline. Thus, if we could estimate \( \frac{\partial z_i}{\partial P_0} \) and \( \frac{\partial F_i}{\partial z_i} \), then we could measure the gasoline–price elasticity of demand for attributes (i.e.,

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\(^3\) The appearance of base year price of gasoline (\( P_0 \)) will be explained later in next section.
### Definition of Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost</td>
<td>$V$</td>
<td>Manufacture's sticker price</td>
</tr>
<tr>
<td>Fuel Efficiency</td>
<td>$F$</td>
<td>Gas mileage measured in kilometer per liter gasoline (Manufacture-provided fuel efficiency is measured at a constant speed of 60 Km/H)</td>
</tr>
<tr>
<td>Styling</td>
<td>$z_{st}$</td>
<td>(Length + width) ÷ height</td>
</tr>
<tr>
<td>Interior Space</td>
<td>$z_{is}$</td>
<td>Interior length + interior width + interior height</td>
</tr>
<tr>
<td>Option Availability</td>
<td>$z_{ob}$</td>
<td>Number of available options; scaled 1–5</td>
</tr>
<tr>
<td>Combustion Capacity</td>
<td>$z_{cc}$</td>
<td>Combustion capacity of engine</td>
</tr>
<tr>
<td>Imported Car (dummy)</td>
<td>$d_{im}$</td>
<td>1 for imported car; 0 otherwise</td>
</tr>
<tr>
<td>Luxury Car (dummy)</td>
<td>$d_{lx}$</td>
<td>1 for luxury car; 0 otherwise</td>
</tr>
</tbody>
</table>

\[
\frac{\partial \ln z_i}{\partial \ln P_0} = \frac{\partial z_i}{\partial P_0} \frac{P_0}{z_i} \quad \text{and the gasoline-price elasticity of demand for fuel efficiency (i.e.,)} \quad \frac{\partial \ln F}{\partial \ln P_0} = \frac{\partial F}{\partial P_0} \frac{P_0}{F}, \quad \text{respectively. Next section explains the procedures for the estimation of the above partial derivatives and elasticities in the Korean automobile market.}

### III. Data and Estimation

The data for the model estimations include 110 noncommercial automobiles with gasoline engine, which were newly introduced in Korea in 2001. Among them, 50 were imported ones. Automobile attributes in consideration include styling, interior space, option availability, and combustion capacity of engine. In model specification of capital cost function, we add two dummy variables identifying imported and luxury...
cars. The variables definitions are appeared in <Table 1>.

In order to select the appropriate functional forms of the capital cost function and fuel efficiency function, we used Box–Cox transformation method (1964). Based on the results of the likelihood ratio test,\(^4\) we chose the log–log form for the both functions expect for the dummy variables.

The specified capital cost function and fuel efficiency function are as follows.

\[
\ln V = a_0 + \sum_i a_i \ln z_i + \sum_j a_j d_j
\]
\[
\ln F = b_0 + \sum_i b_i \ln z_i
\]

And, we assumed a linearly homogeneous Cobb–Douglas subutility function such as \( \ln U = \sum_i c_i \ln z_i \). Since the linearly homogeneity of subutility function requires that \( \sum_i c_i = 1 \), its coefficients of the attribute variables are calculated by the following relationship: \( c_i = \frac{a_i}{\sum a_i} \), implying that each coefficient of the subutility function is equal to its expenditure share in capital cost function.

<Table 2> reports the estimated coefficients of the capital cost and fuel efficiency functions and the calculated coefficients of subutility function. All of the estimated coefficients are statistically significant at the 0.01 level, and the \( R^2 \) of the capital cost function and fuel efficiency function is 0.94 and 0.77, respectively. The Heteroskedasticity problems are not found for these estimated functions.\(^5\)

\(^4\) The \( \chi^2 \)-statistic for the log–log form was 0.26 for the capital cost function and was 0.036 for the fuel efficiency function, while the capital value of 0.01 significance level was 2.265. The SHAZAM package was used for this set.

\(^5\) The Heteroskedasticity tests were conducted by using HET option in the SHAZAM
Table 2  Estimated Coefficient

<table>
<thead>
<tr>
<th>Variable</th>
<th>Capital Cost Function</th>
<th>Fuel Efficiency Function</th>
<th>Subutility Function$^{(b)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-2.7090(8.503)$^{(a)}$</td>
<td>36.884(14.23)</td>
<td></td>
</tr>
<tr>
<td>$z_{st}$</td>
<td>0.28291(2.270)</td>
<td>-0.50332(2.9888)</td>
<td>0.092</td>
</tr>
<tr>
<td>$z_{is}$</td>
<td>1.4524(3.529)</td>
<td>-0.00283(3.908)</td>
<td>0.472</td>
</tr>
<tr>
<td>$z_{op}$</td>
<td>0.43977(4.619)</td>
<td>-2.0378(8.593)</td>
<td>0.143</td>
</tr>
<tr>
<td>$z_{cc}$</td>
<td>0.90297(8.160)</td>
<td>-0.00542(3.745)</td>
<td>0.293</td>
</tr>
<tr>
<td>$d_{im}$</td>
<td>0.66889(9.232)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$d_{is}$</td>
<td>0.45810(5.503)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.94</td>
<td>0.77</td>
<td></td>
</tr>
</tbody>
</table>

Note: a) Numbers in parentheses are $t$-statistics.
   b) Calculated from the Capital Cost Function.

For the comparative-static analysis mentioned above, we utilize the coefficients of the three functions and the values of attributes ($z_{st}, z_{is}, z_{op}, z_{cc}$), fuel efficiency ($F$), the driving mileage ($D_t$), discount rate ($r$), and base year gasoline price ($P_0$). We assume that $P_t = P_0(1 + f)^t$, where $f$ is the expected growth rate of real gasoline price. If we substitute this into the equation (4), the comparative-static analysis with respect to $P_0$ becomes possible. We assumed that the value of $f$ is 0.2 and the value of $r$ is 0.04 by reflecting the increase rate of gasoline price and real interest rate in 2001. The base year gasoline price ($P_0$) was assumed to be 1,278.9 Korean Won per liter. The average driving distance ($D_t$) in 2001 was assumed to be 19,000 Km. The Appendix at the end of this
(Table 3) Estimated Results of Gasoline-Price Elasticities of Demand be Selected Automobile Model

<table>
<thead>
<tr>
<th>Model</th>
<th>Fuel Efficiency (Km/liter)</th>
<th>Elasticities of Attributes Demand</th>
<th>Elasticities of Fuel Efficiency Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Styling</td>
<td>Interior Space</td>
</tr>
<tr>
<td>Daewoo Matiz</td>
<td>22.2</td>
<td>-0.020</td>
<td>-0.017</td>
</tr>
<tr>
<td>KIA Rio 1.3</td>
<td>17.8</td>
<td>-0.031</td>
<td>-0.091</td>
</tr>
<tr>
<td>Hyundai EF Sonata 2.0</td>
<td>14.1</td>
<td>-0.051</td>
<td>-0.061</td>
</tr>
<tr>
<td>KIA Optima 2.5</td>
<td>10.6</td>
<td>-0.014</td>
<td>-0.057</td>
</tr>
<tr>
<td>SM 525</td>
<td>10.3</td>
<td>-0.059</td>
<td>-0.061</td>
</tr>
<tr>
<td>Daewoo Chairman 600S</td>
<td>9.1</td>
<td>-0.046</td>
<td>-0.038</td>
</tr>
<tr>
<td>Toyota LS430</td>
<td>8.3</td>
<td>-0.024</td>
<td>-0.041</td>
</tr>
<tr>
<td>Hyundai EquusL4.5</td>
<td>7.5</td>
<td>-0.016</td>
<td>-0.018</td>
</tr>
<tr>
<td>BMW 540i</td>
<td>6.7</td>
<td>-0.014</td>
<td>-0.066</td>
</tr>
<tr>
<td>Benz S600</td>
<td>5.0</td>
<td>-0.002</td>
<td>-0.014</td>
</tr>
</tbody>
</table>

The paper provides remaining details for the comparative-static analysis.

(Table 3) reports the estimated gasoline-price elasticities of demand for attributes and fuel efficiency for 10 selected automobile models introduced in Korea in 2001. The estimated results indicate that the effects of an increase in gasoline price tend to decrease the demand for styling (longer, lower and wider appearance), interior space, and engine capacity, although the estimated elasticities are very small in absolute values. The implies that the demand for the attributes such as styling, interior space, and engine capacity is largely unaffected by an increase in fuel price.

The effect of gasoline price change on the demand for the option availability (number of options equipped in the car) did not show the same
direction for all models. The magnitudes of the elasticities are also very small though. As the automobile options include air bag, anti-lock brake system (ABS), aluminum wheel, auto-transmission etc., the demand for some of the options might not be affected by gasoline price. Rather, they might determine only an additional capital cost of automobile even without affecting fuel efficiency.

The estimated gasoline price elasticity of demand for fuel efficiency was on the average 0.366 for the 110 models surveyed for this study in 2001. This indicates that the fuel efficiency of new automobiles in Korean market respond inelastically to the changes in expected gasoline prices. The inelastic demand for fuel efficiency with respect to the fuel price implies that the long-run own-price elasticity of demand for gasoline is also inelastic in Korean automobile market.

In comparison of the study of Lee and Lee (2001), this research took place under a premise of the necessity for more concrete empirical analysis with the recent automobile market rapidly changed. In fact, previous studies were limited to the ratio of acceleration, and interior space as variables affecting the decision making of consumers. In addition, the studies may have variance with actual facts as those had the premise that option availability does not have significant mutual impact to mileage or fuel efficiency. Therefore, this analysis includes variables such as option availability, styling of the automobile and combustion capacity of engine to reflect the changes in actual market of automobile and motorization.

In comparison with the result of Lee and Lee (2001) study, which had analyzed data of 1997, the elasticity of demand estimated as less responding ratio for fuel consumption in reaction to the gasoline price. To
consider the gasoline price hike from 5 years ago, it proves the passenger cars in Korean market become larger and high-powered. According to the result of analysis with adding variable of options for automobile, it shows owners of expensive vehicle do not respond to changes on gasoline price, while owners of compact and intermediate level automobile respond negative and changed to cars in lower scale with more options to compensate or increase utility.

A serious policy implication might be drawn from the above results. As long as Korean government tends to keep high price of gasoline in order to reduce to traffic and environmental problems caused by use of automobiles, the policy effects could not be promising. Based on the results of our analysis, increase in gasoline price would not significantly affect demands for automobile attributes in the direction of improving fuel efficiency. Thus other policy alternatives should be sought for the same policy objectives in Korea.

IV. Conclusions

As the number of automobiles has considerably increased during last two decades in Korea, environmental burdens due to traffic congestion and increased gasoline use became a serious problem to be solved by government intervention. In an effort to reduce the social cost associated with this trend, Korean government has placed a high policy priority on keeping high price of consumer price of gasoline. It has been expected that if gasoline price rises, consumers would reduce the quantity
demanded of gasoline and prefer fuel efficient automobiles. However, the effect of such a policy would be highly dependent upon the price elasticity of demand for gasoline and the consumer’s choice for fuel-efficient automobiles.

In this respect, we intended to examine the effects of gasoline price on the pattern of automobile attributes in association with fuel efficiency. By using a Hedonic model, we estimated the elasticities of demand for automobile attributes and for fuel efficiency with respect to price of gasoline by using cross-section data for the 2001 automobile market in Korea.

The estimated results indicate that the demand for the attributes considered in this paper such as styling, interior space, option availability, and engine capacity is largely unaffected by an increase in fuel price. The estimated gasoline price elasticity of demand for fuel efficiency was on the average 0.366 for the 110 models surveyed for this study in 2001, implying that the long-run own-price elasticity of demand for gasoline is also inelastic in Korean automobile market.

As a result, increase in gasoline price would not significantly affect demand for automobile attributes in conjunction with improved fuel efficiency. This indicates that the current Korean government policy by using taxation to keep high consumer price of gasoline would not be an effective measure to reduce the social costs associated with the increasing number of automobiles in Korea.
\section*{Appendix}

The first-order conditions of the Lagrangean function are given below. Hereafter, we follow the conventional way to express partial derivatives, using subscripts $i$ and $j$ to identify each argument in the function.

\begin{align*}
U_i &= \lambda \left[ V_i - \sum_{t=1}^{T} \frac{1}{(1+r)^t} P_t D_t F^{-2} \right] \\
i &= 1, 2, \ldots, n \\
M &= V + \sum_{t=1}^{T} \frac{1}{(1+r)^t} P_t D_t F^{-1}
\end{align*}

Equation (A3) shows the comparative-static equations with respect to the base year price of gasoline ($P_0$).

\[
\begin{bmatrix}
A_{11} & \cdots & A_{1n} & \eta F_1 - V_1 \\
\vdots & \vdots & \vdots & \vdots \\
A_{n1} & \cdots & A_{nn} & \eta F_n - V_n \\
\eta F_1 - V_1 & \cdots & \eta F_n - V_n & 0
\end{bmatrix}
\begin{bmatrix}
\frac{\partial z_1}{\partial P_0} \\
\vdots \\
\frac{\partial z_n}{\partial P_0} \\
\frac{\partial \lambda}{\partial P_0}
\end{bmatrix}
= 
\begin{bmatrix}
-\lambda E_1 \frac{\partial \eta}{\partial P_0} \\
\vdots \\
-\lambda E_n \frac{\partial \eta}{\partial P_0} \\
E \frac{\partial \eta}{\partial P_0}
\end{bmatrix}
\]

where, $A_{ij} = U_{ij} - \lambda (V_{ij} - \eta F_{ij} + 2\eta F^{-1} F_i F_j)$, $i, j = 1, \ldots, n$, and $\eta = \sum_{t=1}^{T} \frac{1}{(1+r)^t} P_t D_t F^{-2}$.

By solving (A3), we can obtain $\frac{\partial z_i}{\partial P_0}$. The partial derivative of fuel efficiency with respect to a change in the gasoline price of base year can
be calculated as follows: \[ \frac{\partial F}{\partial P_0} = \sum_{i=1}^{n} \frac{\partial F_i}{\partial z_i} \frac{\partial z_i}{\partial P_0}. \] In order to calculate the value of \( \frac{\partial F}{\partial P_0} \), we need the estimated values of \( \frac{\partial F_i}{\partial z_i} \) in addition to those of \( \frac{\partial z_i}{\partial P_0} \).

The estimation procedures to obtain \( \frac{\partial F_i}{\partial z_i} \) and values of the variables in equation (A3) are explained below.

By assuming a linearly homogeneous Cobb-Douglas subutility function such as \( \ln U = \sum_i c_i \ln z_i, \sum_i c_i = 1 \).

Log-log forms of the capital cost function and the fuel efficiency function are specified as:

\[
\ln V = a_0 + \sum_i a_i \ln z_i + \sum_j a_j d_j \\
\ln F = b_0 + \sum_i b_i \ln z_i
\]

As we assumed the linear homogeneity of subutility function, its coefficients of the attributes variables are calculated by the following relationship: \( c_i = \frac{a_i}{\sum_i a_i} \), implying that each coefficient of the subutility function is equal to its expenditure share in capital cost function.

Differentiating the estimated capital cost function, fuel efficiency function, and subutility function, we get

\[
V_i = \frac{\partial V}{\partial z_i} = \frac{\partial \ln V}{\partial \ln z_i} \frac{V}{z_i} = a_i \frac{V}{z_i} \\
V_{ii} = \frac{\partial^2 V}{\partial z_i \partial z_j} = - \frac{a_i V}{z_i^2} \quad i = j \\
= 0 \quad i \neq j
\]
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\[ F_i = \frac{\partial F}{\partial z_i} = \frac{\partial \ln F}{\partial \ln z_i} \frac{F}{z_i} = b_i \frac{F}{z_i} \]

\[ F_{ij} = \frac{\partial^2 F}{\partial z_i \partial z_j} = -\frac{b_i F}{z_i^2}, \quad i = j \]

\[ = 0, \quad i \neq j \]

\[ U_{ij} = \frac{\partial^2 \ln U}{\partial z_i \partial z_j} = -\frac{c_i}{z_i^2}, \quad i = j \]

\[ = 0, \quad i \neq j \]

The equations of \( P_t, \eta, \) and \( \lambda \) are given below and their values can be obtained by the assumptions given in the text:

\[ P_t = P_0(1+f)^t, \quad \eta = \sum_{t=1}^{T} \frac{1}{(1+r)^t} P_0 (1+f)^t D_i F^{-2} \]

and \( \lambda = \frac{\sum_i c_i}{\sum_i \left[ \frac{a_i V}{z_i} - \eta \frac{b_i F}{z_i} \right]} \)

Using all the information stated above, we can solve the comparative-static equation and finally estimate the elasticities of demand for attributes and fuel efficiency.

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2. Box, G. E. P. and D. R. Cox, "An Analysis of Transformations," *Journal of the Royal*


Abstracts

헤도니카격기법을 이용한 자동차 속성의 수요탄력성 추정

이성태 · 이광석

본 연구는 헤도니카격기법과 비교과정분석을 사용하여 횡발유가격에 대한 자동차의 연료 효율성과 속성의 수요탄력성을 추정한 것이다. 탄력성을 추정하는 데에는 횡 발유가격에 대한 장기간의 시계열자료 대신 분석의 기준년도인 2001년의 평균 횡발유 가격이 사용되었으며, 그리고 2001년에 한국에서 새로 출시된 110개 자동차 모델에 대한 자료가 이용되었다. 분석의 대상이 되는 자동차의 속성으로는 디자인, 실내공간의 넓이, 엔진 배기량, 장착가능한 편의장치, 그리고 연비 등을 포함시켰다. 횡발유가격에 대한 연료 효율성의 장기적인 수요탄력성은 0.366으로 추정되었다. 그 외의 속성들의 수요탄력성도 비탈력적인 것으로 도출되었다. 따라서, 횡발유가격은 자동차의 속 성들과 연료 효율성의 소비에 큰 영향을 미치지 않는 것으로 해석할 수 있다.