Automobile Prices and Quality Changes: A Hedonic Price Analysis of the Japanese Automobile Market

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As an application of the hedonic approach, this paper provides empirical evidence showing why the Japanese CPI has failed to account for quality changes in automobiles. The paper find first that, between 1990-94, quality-adjusted price index for automobiles declined 0.3 % annually, while the automobile CPI rose 0.6 % ; this decline in the quality-adjusted price index reduced the durable goods CPI by 0.2 % per year, and the overall CPI by 0.01 %. Second, quality-adjusted price indexes for automobiles vary from size to size and from styling to styling, which implies limited coverage and sampling for the automobile CPI may affect the accuracy of the official CPI. Third, the current methodology used in the CPI to cope with quality adjustment in specification changes has failed to account for quality changes between existing and new automobiles; while the hedonic approach has proved to be an effective way to increase the accuracy of quality adjustment.

Key Words : Hedonic Price Index; Quality Changes; Measurement Errors; Automobiles; Multicollinearity; Principal Components.

I. Introduction

As an application of the hedonic approach to the Japanese automobile market, this paper establishes a quality-adjusted price index for new automobiles, and also evaluates the upward bias caused by the lack of appropriate quality adjustment method for automobiles in the Consumer Price Index (CPI).[1]

Many studies have employed the hedonic approach to account for quality changes in the U.S. automobile market.[2] Automobiles are the most popular consumer durables, thus relatively easy to gather detailed information on their functional and performance

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[1]The theoretical foundation and empirical methodology for the hedonic approach are discussed in detail in Shiratsuka (1995). See also Ohta (1980) and Berndt (1991).

[2]The hedonic approach is a method to analyze price-quality relationship by regressing prices on numerous explanatory variables which represent important quality characteristics of a product. Such approach can find its

characteristics. There are also similar studies in Japan, including those of Ohta (1978, 1980, 1987), which have applied the hedonic approach to the Japanese automobile market and compared the computed hedonic price index with the official CPI.[3] However, there have been few follow-up researches in Japan since Ohta's pioneering works which were based on 1970-82 data.

This paper takes up automobiles for two reasons. First, the weight of automobiles in the CPI is the largest among consumer durables, and failure in quality adjustment for automobiles may have a large effect on the accuracy of the CPI. Table 1 shows the CPI weights for automobiles.[4] The weight of automobiles in the overall CPI is 2 % in the case of the national index and 1 % in the Tokyo index. The weight in the durable goods CPI is 31 % in the national index and 23 % in the Tokyo index.[5]

Second, the Japanese automobile market is going through rapid changes, and quality of automobiles has improved substantially. For example, in the Japanese automobile

Table 1
CPI Weights of Automobiles

(%)

	Overall		Among durables		
Items	National	Tokyo	National	Tokyo	
Automobiles	1.8	1.1	31.3	22.6	
Mini cars	0.2	0.1	2.8	2.0	
Small cars A	0.3	0.2	5.9	4.3	661-1500cc
Small cars B	0.5	0.3	7.9	5.7	1501-1900cc
Small cars C	0.7	0.5	12.6	9.1	1900-2000cc
Small imported cars	0.1	0.1	2.1	1.5	1700-2000cc

origin in Waugh (1928), which applied it to vegetable prices. Court (1939) attempted to capture automobile's various characteristics which will bring consumers pleasure and comfort, and named this approach "hedonic." See also Griliches (1961), Ohta and Griliches (1976, 1986), and Gordon (1990) for other applications to automobile price analysis.

[3]His conclusion was that although there are only minor differences between the general movement of the overall CPI and the associated hedonic price index (which makes adjustment for quality changes for cars), the estimated hedonic parameter should be used to produce a reliable price index by making quality adjustment when the sampling items included in the price index are changed. Ohta (1987) estimated a hedonic price index for used cars using the 1970-83 data and compared it with the new car price index.

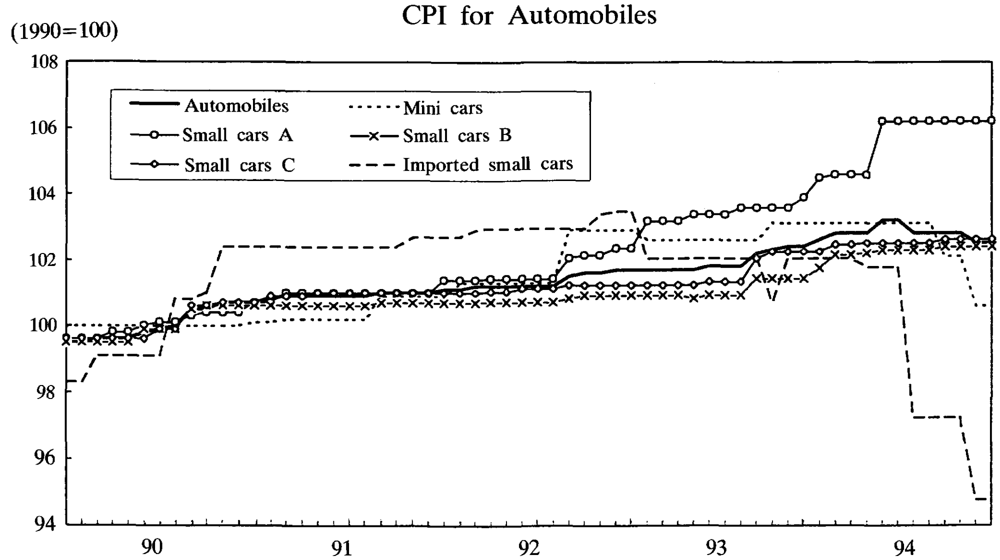
[4]Japanese automobiles are categorized into three classes: standard car (over 2,000cc in engine displacement), small car (661cc to 2,000cc), and mini car (660cc and under).

[5]Some point out problems in the sampling and coverage of the data in the Family Income and Expenditure Survey from which the CPI weights are calculated. Moreover, the share of cars in the durable consumer goods changes substantially from year to year, and the weights of the durable goods may either overestimate or underestimate the real share depending on the choice of the base year.

market, particularly from the late 1980s to the early 1990s, large upscale models were much in demand.[6] This strong demand was due mainly to a shift in consumer preferences toward larger luxury automobiles and a tax reduction for larger standard cars, so-called "3-number" automobiles.[7] In addition, consumer preferences seem to have diversified and various RV(recreational vehicle)-type vehicles such as station wagons, minivans, and off-road vehicles have been selling extremely well. At the same time, many improvements in performance and safety levels have been achieved as a result of the introduction of new electronic equipment such as automatic engine and suspension control systems, car navigation equipment, and air bags.

Figure 1 shows the CPIs for automobiles in the Tokyo area, which are adjusted for the changes in the consumption tax rates.[8] The overall automobile price index (indicated by the thick line) shows a mild upward trend from 1990 to mid-1994, but it seems to have

Figure 1
CPI for Automobiles



Sources: Consumer Price Index, Management and Coordination Agency.
Note: Price indexes are adjusted for changes in the consumption tax rates.

[6]In more recent years, however, with the introduction of low-priced import cars and the adverse effects of the collapse of the bubble economy, price competition seems to have intensified. As a result, the increased trend for larger luxury cars appears to have subsided somewhat.

[7]"3-number" car is a nickname of a standard car, which has over 2,000 cc engine displacement; a double digit number beginning with "3" shown on the license number plate.

[8]At the time of the introduction of consumption taxes, the tax rate for standard and small cars was initially set at 6 % while the normal consumption tax rate was 3 %. This was designed to offset the reduction in tax revenue due to the abolition of the commodity taxes levied on automobiles. However, the tax rate for cars was reduced to 4.5 % in April 1992 and to 3 % in April 1994.

been stable since then. This trend, however, does not seem to be consistent with the public image that the price competition has intensified in the Japanese automobile market and the automobile prices have fallen in recent years. The only exception is imported automobiles, whose price index has fallen sharply since mid-1994.

The difference between the CPI movements and the public image of automobile prices, mentioned above, may suggest that the CPI is upwardly biased for the following two reasons.[9] First, the automobiles CPI does not keep up with quality changes. It fails to cover the effects of quality changes. Second, the sampling coverage is limited and the number of samples is small.[10] For example, standard cars are not included in the CPI as it covers only five categories of automobiles ranging from mini cars to small cars. In addition, the detailed information about the automobile models surveyed in the CPI is not made public by the Management and Coordination Agency, which constructs the CPI. Thus, we do not know how the various kinds of automobiles are actually grouped and selected in the process of sampling automobiles in the market.[11]

The contents of this paper are as follows. Section II discusses the data set; specifically, the data construction method, its time-series characteristics, and some potential problems. Sections III and IV examine the adjustment methods for quality changes in constructing a reliable price index for automobiles.

Specifically, Section III shows that the failure in quality adjustment for automobiles has produced the same degree of upward bias as that for personal computers in the CPI. The section estimates a hedonic function for automobiles, and shows that the quality-adjusted price index for automobiles (the hedonic price index) declined at an annual rate of 0.3 % between 1990-94. During the same period, the CPI for automobiles rose at an annual rate of 0.6 %, after making adjustments for the consumption tax rate changes. This decline in the quality-adjusted price index reduces the durable goods CPI by 0.2 % per year and the overall CPI by 0.01 %. These are almost the same as the estimates of Shiratsuka (1995) for personal computers. This bias, moreover, seems to have increased in more recent years because the quality-adjusted price index has fallen since 1993 after rising between 1991-92. The bias after 1993 is, in fact, estimated to be in the range of 0.3-0.4 % for the durable goods CPI and around 0.02 % for the overall CPI.

Section III also presents results of estimation for hedonic functions for different size and styling automobiles in the sample. The results show that quality-adjusted price changes among sizes and stylings are substantially different, which implies that limited coverage and sampling for the automobiles CPI have increased the bias.

Section IV discusses the methodology of applying the hedonic approach to conven-

[9]Section IV will discuss the problems and the methodology of quality adjustment for the CPI.

[10]A question arises as to what is the average basket in the case of an overall price index. But this question is unlikely to become a serious problem in the case of a product price index like cars.

[11]Although the sample selection is said to reflect the number of new car registrations so that it remains representative, details are not made public.

tional price indexes such as the CPI and Wholesale Price Index (WPI). Simulation is conducted to compare the accuracy of quality adjustment methods between the official CPI and the hedonic approach. The result shows that the quality adjustment methods used in the official CPI fail to account for quality changes.[12]

Section V summarizes the major results of this paper and proposes some measures which cover market changes to increase the accuracy of the CPI.

Appendix discusses the problem of selecting explanatory variables to minimize the effects of multicollinearity. It also examines the effectiveness of multivariate analysis on grouping automobiles.

II. Data

This section discusses the method of data construction, the time-series movements of performance characteristics, and some potential problems in the data set.

A. Method of Data Construction

1. *Data coverage*

The basic data on automobile prices and their characteristics are obtained from the *Japanese Motor Vehicles Guide Book* (hereafter, *Guide Book*), which is edited by the Japan Motor Industrial Federation, Inc. This book contains information about the functional and performance characteristics as well as retail list prices of new automobiles (excluding taxes, insurance premiums, and registration fees) in the Tokyo area in October each year. When prices are not listed in the *Guide Book*, they are obtained from the October issues of *Red Book* published by the Auto Guide Corporation, which lists monthly automobile prices. When characteristics and optional equipment are not listed, they are obtained from various automobile catalogues collected by the library of the Japan Motor Industrial Federation, Inc.[13]

The data set covers all categories listed as automobiles in the *Guide Book*, ranging from family cars such as sedans and hatchbacks, to the sports cars such as coupes and hardtops, and to RV-type vehicles such as station wagons, minivans, and 4 wheel-drive (4WD) off-road vehicles. The sizes cover mini, small, and standard cars. However, the data excludes imported automobiles because their data are not available in the *Guide*

[12]The direct comparison method and the price link method are mainly used at the time of specification changes of the items surveyed in the official CPI. In the direct comparison method, the rate of change in the price index is the same as that in the nominal prices between the old products and new products, or it assumes no quality changes between them. In the price link method, the rate of change in the price index is zero, or it assumes that the change between the new and old product price fully reflects the quality difference.

[13]Samples without complete information on prices and performance characteristics are excluded from the data set. Ohta (1978, 1980, 1987) has also used the data from the *Guide Book* and *Red Book*.

Book.[14,15]

In addition to automobile prices, the data set contains eleven performance characteristics (body size, interior space, maximum power, and torque, etc.), seven options (air conditioning, auto air conditioning, anti-lock braking system, etc.), automobile styling (sedan, hatchback, hardtop, etc.), automobile size (standard, small, mini), engine types (gasoline- or diesel-fueled as well as V-type, straight, rotary, etc.), power wheels (FR, FF, and 4WD), transmissions (5-speed floor shift, 4-speed automatic, etc.). These characteristics are represented as dummy variables in estimations. The sample period is five years from 1990 to 1994, and the sample size in each year is approximately 500.

2. *Time-series movements of characteristics*

Table 2 shows the time-series movement of the averages of prices, performance characteristics and options as well as changing shares by automaker, size, and styling.[16] The table shows the movements toward larger luxury automobiles and RV-type vehicles, and they are consistent with the recent developments in the Japanese automobile market reported in Section I.

First, the table indicates the trend of consumer preferences toward larger luxury automobiles. All the indicators of automobile size such as weight, length, width, and height rose. The performance characteristics such as maximum power, torque, engine displacement all increased at an annual rate of about 3 %. The trend toward larger automobiles is also seen in the increasing share of standard cars (so-called "3-number" automobiles) and the declining share of small cars. Furthermore, the share of automobiles with air conditioning, auto air conditioning, an anti-lock braking system, and an air bag all rose, indicating the general trend toward upper class and more functional equipment. With the increase in the performance characteristics, the average price of samples increased at an annual rate of 4 % between 1990-94; in particular, it rose sharply between 1990-92 and then slowed between 1993-94.

Second, the increased popularity of RV-type vehicles is seen in the table. For example, the share of station wagons and off-road vehicles rose while the share of sedans fell.

14Foreign-made Japanese cars, which are produced in the foreign plants of Japanese automakers, are included in the data set, because they are listed in the *Guide Book*.

15Ideally, imported foreign cars should be included in the data set particularly because a stronger yen led to the increased import of low priced foreign-made cars. Unfortunately there are no readily available data sources for foreign imported cars which are comparable to those in the *Guide Book*. The present paper, therefore, does not include foreign imported cars. The analysis of the price index including foreign imported cars is left to future research.

16Options are represented as a dummy variable: 1 for cars with the option and 0 for cars without. Therefore, averages represent the share of cars with the option. However the value of the air bag option represents the number of air bags in the car so that, precisely speaking, it does not represent the share of cars with an air bag.

Table 2
Average Prices and Performance Characteristics

Variables	Units	1990	1991	1992	1993	1994	Rate of changes
Price	(thousand yen)	1,888.1	2,032.9	2,134.9	2,154.9	2,204.5	3.949
Width	(m)	4.256	4.276	4.289	4.285	4.326	0.409
Length	(m)	1.652	1.662	1.665	1.669	1.679	0.405
Height	(m)	1.455	1.461	1.471	1.477	1.484	0.489
Interior space	(m^3)	3.130	3.160	3.191	3.186	3.227	0.764
Wheelbase	(m)	2.481	2.503	2.514	2.521	2.541	0.605
Weight	(t)	1.195	1.211	1.238	1.240	1.269	1.518
Seating capacity	(persons)	5.074	5.066	5.092	5.052	5.089	0.074
Fuel economy	(km/l)	20.745	20.538	20.690	20.918	20.397	-0.422
Engine displacement	(thousand cc)	1.801	1.869	1.912	1.940	1.987	2.494
Max power	(hundred HP)	1.217	1.287	1.307	1.330	1.381	3.217
Torque	(kg*m)	17.251	17.697	18.088	18.350	19.195	2.705
Air conditioner		0.125	0.142	0.188	0.253	0.244	
Auto air conditioner		0.295	0.453	0.559	0.579	0.602	
Anti-lock brake		0.123	0.158	0.176	0.156	0.171	
4WS		0.049	0.033	0.034	0.032	0.012	
Air bags		0.015	0.070	0.096	0.098	0.144	
Sunroof		0.113	0.123	0.118	0.128	0.136	
Car navigation		0.004	0.010	0.006	0.006	0.002	
Number of sample		475	488	506	508	498	
Toyota	(%)	20.0	18.7	18.0	19.4	20.3	
Nissan	(%)	18.7	18.3	17.4	16.4	17.1	
Mitsubishi	(%)	12.7	14.8	16.0	14.2	14.2	
Mazda	(%)	12.5	9.5	11.6	11.8	11.6	
Honda	(%)	10.4	10.5	8.4	9.8	10.8	
Others	(%)	4.0	6.2	5.6	3.6	4.1	
Standard car	(%)	19.7	25.3	35.1	42.7	44.7	
Small car	(%)	69.6	64.2	52.3	44.1	43.7	
Mini car	(%)	10.6	10.5	12.6	13.2	11.6	
Sedan	(%)	31.8	31.5	26.3	25.0	26.4	
Hatchback	(%)	23.8	23.0	23.2	23.6	19.7	
Coupe	(%)	10.8	11.5	10.0	9.4	10.4	
Hardtop	(%)	13.4	12.3	15.8	15.6	15.0	
Station wagon	(%)	7.6	7.0	8.2	9.0	10.0	
Minivan	(%)	8.9	9.1	9.4	8.6	8.3	
Off-road vehicle	(%)	3.6	5.6	7.0	9.0	10.2	

3. Potential problems with the data set

There are two potential problems with the data set. First, price data are limited to list prices in the Tokyo area. Therefore, prices may not accurately reflect actual trading prices, which tend to be discounted from list prices, depending on the trading conditions, such as class of an automobile to be purchased, kind of a trade-in automobile, method of payment, and timing of model change of competing automobiles. Consequently, prices in the data set may overstate actual automobile prices, and this point needs to be kept in mind when empirical results are interpreted. Nevertheless, use of list prices makes it possible to obtain a wide range of samples on a uniform basis. Thus, this seems to more than offset the disadvantages mentioned above.

Second, the listed samples in the *Guide Book* may be biased. Although the *Guide Book* is a very valuable data source, covering a wide range of automobiles, the selection standard of automobiles listed seems to be different across years and automakers. In particular, automobile prices differ substantially even for the same model, depending on standard equipment and options. Therefore, there is a possibility that the sample prices are biased. Nevertheless, I think it better to maximize the informational value of the data in the *Guide Book* by using them without any arbitrary adjustments.[17] This is because sizes and stylings have been greatly diversified in recent years as represented by the recent popularity of "3-number" cars and RV-type vehicles.

In order to minimize the effects of a possible sampling bias, this paper attempts to average out the sample structure by pooling several annual data.[18] However, pooling data for several years may risk losing the stability of estimated parameters when the fundamental conditions behind the supply and demand for automobiles such as technical innovations, factor prices, and consumer preferences, have changed. Therefore, it is necessary to check the stability of estimated parameters by comparing estimation performance across estimations with different sample periods.

B. Specification of Characteristics

The estimation of a hedonic function requires collecting data on the functional and performance characteristics that are likely to have strong explanatory power for product prices. In many cases, those characteristics tend to exhibit high multicollinearity. In the

[17]To minimize the effects of "omitted characteristics," the data set excluded the special purpose models in the *Guide Book*. For example, top of market cars like the Toyota Century, open cars, and down-market business cars are excluded. See Ohta (1980) for the problem of "omitted characteristics."

[18]Another way to minimize the effects of a possible bias is to maintain the same sample structure by selecting identical car models every year. For example, using this method, Ohta and Griliches (1976) created a data set for estimation. However, it did not resolve the problem of time-series parameter instability partly due to multicollinearity. Moreover this method does not seem to be appropriate for the purpose of the present study because it would fail to reflect the recent diversification of car size and styling, and would introduce arbitrariness in the sample selection.

case of automobiles, although the data are relatively easy to collect, the problem of multicollinearity is particularly serious.

Table 3 shows correlation coefficients for the aforementioned eleven performance characteristics. The correlation coefficients between interior space and seating capacity, and between engine displacement and torque are both above 0.9. Many others also show high correlation coefficients around 0.7-0.9. For example, many characteristics related to a automobile size such as automobile length, width, height, wheel base, and interior space exhibit a high correlation predictably. Furthermore, it is not surprising that larger automobiles tend to be heavier and to consume more fuel, because they tend to have larger engines.

In order to minimize the problem of multicollinearity and obtain highly reliable estimates, it is quite important to select some performance characteristics with high explanatory power out of the possible explanatory variables.[19] However, as discussed in detail in Appendix 1, all characteristics are involved in high degree of multicollinearity, which cannot be completely eliminated even by careful selection of basic characteristics. Therefore, basic characteristics should be selected for estimating the hedonic function by comparing the stability of estimations among different combinations of those characteristics. In this sense, I classify performance characteristics into three main categories, engine power, automobile size, and interior size, and then select the explanatory variables of characteristics, comparing the goodness of fit and stability of estimated parameters.

Table 3
Correlation Among Performance Characteristics

	Width	Length	Height	Interior space	Wheel-base	Weight	Seating capacity	Fuel consump-tion	Engine displace-ment	Max power	Torque
Width	1.000										
Length	0.898	1.000									
Height	-0.014	0.034	1.000								
Interior space	0.405	0.306	0.715	1.000							
Wheelbase	0.819	0.679	-0.177	0.207	1.000						
Weight	0.727	0.756	0.530	0.603	0.530	1.000					
Seating capacity	0.370	0.293	0.686	0.912	0.201	0.537	1.000				
Fuel consumption	-0.701	-0.716	-0.334	-0.412	-0.495	-0.853	-0.353	1.000			
Engine displacement	0.784	0.831	0.235	0.380	0.620	0.900	0.328	-0.837	1.000		
Max power	0.691	0.697	-0.230	0.008	0.599	0.559	-0.065	-0.690	0.744	1.000	
Torque	0.719	0.764	0.125	0.259	0.570	0.825	0.183	-0.801	0.907	0.879	1.000

[19]The analysis of principal components provides another method for resolving the multicollinearity problem. Although the details are left to Appendix 1, the finding is that an improvement in estimation performance is so small that it does not merit adopting the method.

The final selection of characteristics as explanatory variables is presented in Table 4. The following three variables are selected as main performance characteristics: maximum power represents the engine power; wheelbase represents the automobile size; and interior space represents the interior size. Six dummy variables on the optional functions are added to adjust for functional options: the presence of air conditioning, auto air conditioning, anti-lock brakes, a 4-wheel steering (4WS), air bags, a sunroof, car navigation equipment. In addition, six kinds of dummy variables adopted for tracing the functional and performance characteristics that are difficult to quantify: automobile styling (sedan, hardtop, station wagon, etc.), automobile size (standard, small, and mini), engine type (gasoline and diesel; and V, straight, and rotary), transmission (4-

Table 4
Explanatory Variables in Hedonic Function

Explanatory variables	Definitions
(Characteristics)	
Maximum power	Maximum horse power of engine in net basis (Unit: thousand horse power)
Wheelbase	Length between front and back wheel (Unit: m)
Interior space	Room length * Room width * Room height (Unit: m^3)
(Dummy variables)	
Air conditioner	1 with air conditioner, 0 without
Auto air conditioner	1 with auto air conditioner, 0 without
Anti-lock brake	1 with anti-lock brake, 0 without
4WS	1 with 4WS, 0 without
Air bags	1 with air bag system for driver's seat, 2 with them for driver's and navigator's seats, 0 without
Car navigation equipment	1 with car navigation system, 0 without
Styling classification	A car styling classification dummy with sedan as a standard base
Size classification	A size classification dummy with small cars as a standars base
Engine type	An engine type dummy with a straight gasoline-fueled engine as a standard base
Transmission	A transmission dummy with 5-speed manual as a standard base
Drive train	A drive train type dummy with FR as a standard base
Automaker	An automaker dummy with Toyota as a standard base
Year	An year dummy with 1990 as a standard base

speed automatic, 5-speed floor shift, etc.), drive train (FR, FF, and 4WD), and automaker (Toyota, Nissan, Mitsubishi, etc.) are added as dummy variables.[20] Year dummies are also added to some of the estimations, when necessary.

III. Empirical Results

This section estimates the hedonic function for the Japanese automobile market,[21] and examines the impact of failure to take full account of quality changes in automobiles on the CPI and potential problems due to the limited coverage and sample number of the current CPI for automobiles.

A. Selection of the Functional Form

Most of the previous studies have assumed that a hedonic function for automobiles is either a semilog linear form or linear form. For example, Ohta (1978, 1980, 1986) and Gordon (1990) used a semilog linear form while Arguea and Hsiao (1993) used a linear form. The Box-Cox test is often used for the statistical test for the goodness of fit among different functional forms.[22]

Table 5 shows the estimations of three functional forms: the Box-Cox transformation, semilog linear, and linear forms. According to these results, although the log-likelihood is highest for the Box-Cox transformation form, it is very near to that of the semilog linear form. The χ^2 test for the null hypothesis that the estimated parameters for the Box-Cox transformation form are equivalent to those for semilog linear form produces 119.2, which is far larger than the critical value of 3.8 at the 5 % level.

The above statistical results do not support the semilog linear form. Nevertheless, Table 5 also shows that the estimated parameters of both the Box-Cox transformation form and the semilog linear form have a positive signs for three basic characteristics, which is consistent with the theoretical prediction.[23] Although the dummy variable for Honda has an opposite sign, it is not statistically significant. Therefore, both the Box-

[20]These unquantifiable dummy variables may be interpreted as capturing the effects of "omitted characteristics," which cannot be measured by means of quantifiable characteristics and the presence or absence of options.

[21]Estimation was effected by LIMDEP version 6.0.

[22]In general, in evaluating the goodness of fit for estimated regressions, one checks the coefficient of determination. However, this will not work when one is comparing the goodness of fit for different functional forms. The Box-Cox test is used in such a case. Shiratsuka (1995) discusses in detail in Appendix A the method of checking the functional forms of a hedonic function, and points out possible statistical and theoretical problems of the Box-Cox test. Therefore it is necessary to judge not only by the Box-Cox test result, but also by the theoretical consistency of estimated parameters, the meaning of estimation results, and the estimation cost.

[23]Table 5 shows that the estimated parameter for the mini car dummy is not statistically significant. This result however is due to the fact that the Box-Cox estimation results are not adjusted for the effects of heteroskedasticity on standard errors. In fact, the estimated hedonic function in Table 6 shows that the estimated parameter for mini cars is statistically significant at the 1 % level.

Table 5
Comparison of Estimations for Box-Cox Transformation, Semilog Linear, and Linear Forms

	Box-Cox transformation		Semilog linear		Linear	
(Transformation parameters)						
Dependent variable	0.276	(0.025 **)	0		1	
Independer variables	1		1		1	
Log likelihood	-16,515.9		-16,575.4		-16,927.6	
Sum of sqrared residual	1,864.19		30.73		1.446E+08	
(Estimated parameters)						
Constant	13.159	(0.960 **)	6.704	(0.782 **)	404.690	(84.4 **)
Maximum power	3.034	(0.577 **)	0.374	(0.081 **)	785.180	(191.1 **)
Wheelbase	2.230	(0.451 **)	0.283	(0.066 **)	513.300	(130.1 **)
Interior space	0.415	(0.093 **)	0.049	(0.012 **)	120.200	(31.1 **)
Air conditoner	0.404	(0.102 **)	0.045	(0.014 **)	127.150	(37.2 **)
Auto air conditioner	0.755	(0.149 **)	0.098	(0.027 **)	163.050	(42.9 **)
Anti-lock brake	0.830	(0.182 **)	0.086	(0.025 **)	303.690	(82.0 **)
4WS	0.607	(0.154 **)	0.079	(0.026 **)	137.160	(45.8 **)
Air bags	0.540	(0.132 **)	0.051	(0.017 **)	238.660	(67.7 **)
Sunroof	0.393	(0.097 **)	0.050	(0.015 **)	97.600	(30.5 **)
Car naviagation	1.362	(0.385 **)	0.128	(0.051 **)	667.560	(202.4 *)
Hatchback	-0.589	(0.117 **)	-0.094	(0.026 **)	-46.042	(20.6 **)
Coupe	0.504	(0.123 **)	0.060	(0.021 **)	132.430	(39.7 **)
Hardtop	0.309	(0.085 **)	0.037	(0.013 **)	80.555	(26.7 **)
Station wagon	0.401	(0.107 **)	0.053	(0.016 **)	78.831	(28.7 **)
Minivan	0.943	(0.245 **)	0.122	(0.035 **)	197.210	(66.6 **)
Off-road vehicle	1.406	(0.284 **)	0.171	(0.049 **)	359.880	(97.0 **)
Standard car	0.628	(0.140 **)	0.067	(0.020 **)	206.060	(55.9 **)
Midget car	-0.033	(0.086)	-0.038	(0.026)	144.300	(45.0 **)
Diesel	1.085	(0.220 **)	0.135	(0.034 **)	267.230	(69.7 **)
V8 gasoline-fueled	2.133	(0.509 **)	0.166	(0.054 **)	1,262.900	(359.3 **)
V6 gasoline-fueled	0.468	(0.115 **)	0.051	(0.018 **)	159.640	(46.5 **)
Rotary	1.705	(0.427 **)	0.172	(0.059 **)	685.610	(197.5 **)
4-speed automatic	0.793	(0.151 **)	0.104	(0.028 **)	172.070	(45.1 *)
4-speed manual	-1.312	(0.253 **)	-0.222	(0.058 **)	-90.452	(43.9 **)
FF	-0.576	(0.132 **)	-0.065	(0.019 **)	-182.250	(49.7 **)
4WD	0.487	(0.109 **)	0.071	(0.022 **)	68.030	(26.1 **)
Nissan	0.293	(0.084 **)	0.036	(0.012 **)	75.570	(26.0)
Mitsubishi	0.016	(0.069)	0.007	(0.009)	-22.614	(20.7 *)
Mazda	0.007	(0.074)	0.010	(0.010)	-47.838	(25.4 *)
Honda	-0.049	(0.079)	0.001	(0.010)	-54.782	(27.3)
Isuzu	0.197	(0.104 *)	0.030	(0.015 *)	18.876	(27.6)
Fuji	-0.275	(0.090 **)	-0.043	(0.017 **)	-30.442	(23.4)
Daihatsu	-0.090	(0.090)	-0.010	(0.012)	-28.121	(26.0)
Suzuki	-0.016	(0.111)	-0.010	(0.015)	30.867	(31.9)
1991	-0.045	(0.058)	-0.003	(0.007)	-20.674	(16.9)
1992	0.051	(0.059)	0.012	(0.008)	-9.093	(16.7 *)
1993	-0.055	(0.062)	-0.001	(0.008)	-37.897	(19.6 **)
1994	-0.150	(0.070 *)	-0.011	(0.009)	-68.403	(24.9 **)

Note: ** and * indicate statistical significance at the 1 and 5 % level, respectively.

Cox transformation form and the semilog linear form should produce similar results. Furthermore, advantages with respect to the semilog linear form are that the exponential transformation of the estimated parameter for year dummies will produce a price index, and that standard errors can be used directly as the standard deviations of the price index.[24,25]

B. Basic Estimation

To check the stability of estimated parameters through time, hedonic functions for each of the three subsets of the 1990-94 data are estimated: full sample estimation which pools all the data, 2-year sample estimations which use data for two adjacent years, and 1-year sample estimations which use data for a single year.

1. Results of estimation

The results of estimation of a hedonic function for automobiles are summarized in Table 6-1, 2, and they indicate high reliability for each sample period. The coefficient of determination adjusted for the degree of freedom is around 0.94 for each regression. The estimated parameters for characteristics have all the right signs and most are statistically significant at the 1 % level. The estimated parameters for dummy variables are also statistically significant except for the automaker dummies.

The estimated parameters for maximum power and interior space show stable movement throughout the sample period, but that for wheelbase tends to fall after 1992. In principle, the wheelbase size is technically constrained by its weight and maneuverability, although a longer wheelbase provides more comfort to passengers. In recent years, however, the cost of increasing wheelbase length is believed to be coming down because of improvements in automobile body materials and suspension systems. These developments on the supply side might have contributed to the recent fall in the estimated parameter for wheelbase.

The following observations on the estimated parameters for dummy variables of optional functions should be noted: (1) The estimated parameters for dummy variables of optional functions seem to be very stable especially for the 2-year data set. Thus, the increased number of options seems to have contributed to the increased automobile prices in recent years. (2) As for styling dummies, the estimated parameters for station wagons and minivans display upward trends. This seems to reflect the increased popularity of RV-type vehicles. (3) In addition, hatchbacks have negative and statistically significant parameters, while other types have positive parameters. (4) Regarding transmission systems, the front-engine and front-wheel drive (FF) car dummy shows negative

[24]See Appendix C of Shiratsuka (1995) for the method to derive a price index from an estimated hedonic function.

[25]The standard error of an estimated parameter for a year dummy can be interpreted as a ratio, because $\ln(1+x)$ approximately holds when x is close to zero.

Table 6-1
Results of Hedonic Functions

	Full sample	2-year sample			
		1990-91	1991-92	1992-93	1993-94
Constant	5.998 (0.063 **)	5.602 (0.115 **)	5.919 (0.102 **)	6.247 (0.094 **)	6.270 (0.087 **)
Max power	0.374 (0.009 **)	0.388 (0.017 **)	0.380 (0.015 **)	0.376 (0.014 **)	0.355 (0.013 **)
Wheelbase	0.283 (0.027 **)	0.405 (0.052 **)	0.299 (0.044 **)	0.175 (0.039 **)	0.197 (0.036 **)
Inerior space	0.049 (0.008 **)	0.069 (0.013 **)	0.056 (0.013 **)	0.055 (0.012 **)	0.043 (0.011 **)
Air conditoner	0.045 (0.009 **)	0.035 (0.014 **)	0.045 (0.015 **)	0.044 (0.015 **)	0.044 (0.015 **)
Auto air conditioner	0.098 (0.007 **)	0.092 (0.011 **)	0.102 (0.011 **)	0.112 (0.012 **)	0.112 (0.014 **)
Anti-lock brake	0.086 (0.008 **)	0.059 (0.014 **)	0.078 (0.012 **)	0.090 (0.012 **)	0.099 (0.013 **)
4WS	0.079 (0.011 **)	0.092 (0.015 **)	0.063 (0.016 **)	0.053 (0.017 **)	0.049 (0.019 **)
Air bags	0.051 (0.007 **)	0.044 (0.017 **)	0.043 (0.011 **)	0.049 (0.010 **)	0.056 (0.010 **)
Sunroof	0.050 (0.009 **)	0.075 (0.014 **)	0.071 (0.014 **)	0.043 (0.013 **)	0.030 (0.013 *)
Car navigation	0.128 (0.025 **)	0.163 (0.048 **)	0.158 (0.043 **)	0.110 (0.027 **)	0.127 (0.023 **)
Hatchback	-0.094 (0.009 **)	-0.096 (0.012 **)	-0.098 (0.013 **)	-0.082 (0.014 **)	-0.077 (0.014 **)
Coupe	0.060 (0.010 **)	0.084 (0.016 **)	0.056 (0.016 **)	0.055 (0.016 **)	0.042 (0.016 **)
Hardtop	0.037 (0.006 **)	0.030 (0.011 **)	0.033 (0.010 **)	0.042 (0.010 **)	0.038 (0.010 **)
Station wagon	0.053 (0.010 **)	0.025 (0.016)	0.039 (0.016 **)	0.065 (0.015 **)	0.068 (0.014 **)
Minivan	0.122 (0.029 **)	0.092 (0.049 *)	0.086 (0.046 *)	0.085 (0.040 *)	0.124 (0.037 **)
Off-road	0.171 (0.016 **)	0.204 (0.034 **)	0.156 (0.027 **)	0.152 (0.022 **)	0.156 (0.023 **)
Standard car	0.067 (0.008 **)	0.072 (0.015 **)	0.085 (0.014 **)	0.088 (0.012 **)	0.074 (0.012 **)
Mini car	-0.038 (0.012 **)	-0.031 (0.018 *)	-0.030 (0.019)	-0.038 (0.020 *)	-0.053 (0.019 **)
Diesel	0.135 (0.013 **)	0.121 (0.021 **)	0.100 (0.022 **)	0.140 (0.020 **)	0.190 (0.020 **)
V8 gasoline-fueled	0.166 (0.017 **)	0.124 (0.032 **)	0.117 (0.030 **)	0.167 (0.026 **)	0.213 (0.023 **)
V6 gasoline-fueled	0.051 (0.008 **)	0.051 (0.015 **)	0.025 (0.014 *)	0.042 (0.013 **)	0.068 (0.013 **)
Rotary	0.172 (0.024 **)	0.154 (0.045 **)	0.171 (0.032 **)	0.164 (0.033 **)	0.199 (0.034 **)
4-speed automatic	0.104 (0.006 **)	0.094 (0.009 **)	0.110 (0.009 **)	0.107 (0.009 **)	0.096 (0.009 **)
4-speed floor	-0.222 (0.021 **)	-0.192 (0.027 **)	-0.219 (0.033 **)	-0.237 (0.047 **)	-0.262 (0.030 **)
FF	-0.065 (0.008 **)	-0.040 (0.013 **)	-0.061 (0.013 **)	-0.070 (0.013 **)	-0.080 (0.013 **)
4WD	0.071 (0.009 **)	0.087 (0.014 **)	0.087 (0.014 **)	0.073 (0.015 **)	0.042 (0.015 **)
Nissan	0.036 (0.007 **)	0.039 (0.012 **)	0.045 (0.012 **)	0.052 (0.011 **)	0.019 (0.011)
Mitsubishi	0.007 (0.010)	0.023 (0.016)	0.013 (0.015)	-0.004 (0.015)	-0.009 (0.015)
Mazda	0.010 (0.009)	0.028 (0.014 *)	0.024 (0.015)	0.003 (0.015)	-0.019 (0.015)
Honda	0.001 (0.009)	0.004 (0.013)	0.002 (0.015)	0.009 (0.015)	0.000 (0.014)
Isuzu	0.030 (0.014 *)	0.052 (0.020 **)	0.053 (0.019 **)	0.023 (0.022)	-0.031 (0.019)
Fuji	-0.043 (0.010 **)	-0.053 (0.017 **)	-0.048 (0.017 **)	-0.029 (0.015 *)	-0.020 (0.015)
Daihatsu	-0.010 (0.011)	-0.016 (0.017)	0.007 (0.017)	-0.004 (0.018)	-0.020 (0.018)
Suzuki	-0.010 (0.014)	0.032 (0.022)	0.007 (0.023)	-0.037 (0.023)	-0.039 (0.024 *)
1991	-0.003 (0.007)	-0.007 (0.007)			
1992	0.012 (0.008)		0.013 (0.007 *)		
1993	-0.001 (0.008)			-0.014 (0.007 *)	
1994	-0.011 (0.008)				-0.007 (0.007)
Adjusted R^2	0.940	0.942	0.940	0.941	0.942
SSR	30.733	11.393	12.131	12.022	11.326
Number of sample	2,449	957	985	1,000	993

Note: White's (1980) heteroskedasticity-robust standard errors in parentheses, because the presence of heteroskedasticity is judged by Breusch-Pagan (1979) test; ** and * indicate statistical significance at the 1 and 5 % level, respectively.

Table 6-2
Results of Hedonic Functions (continued)

	1-Year Sample				
	1990	1991	1992	1993	1994
Constant	5.508 (0.157 **)	5.625 (0.143 **)	6.206 (0.143 **)	6.238 (0.121 **)	6.312 (0.118 **)
Max power	0.394 (0.023 **)	0.381 (0.024 **)	0.377 (0.019 **)	0.380 (0.019 **)	0.333 (0.018 **)
Wheelbase	0.425 (0.077 **)	0.414 (0.062 **)	0.188 (0.061 **)	0.164 (0.051 **)	0.209 (0.051 *)
Interior space	0.080 (0.021 **)	0.056 (0.017 **)	0.057 (0.017 **)	0.059 (0.014 **)	0.034 (0.015 *)
Air conditioner	0.023 (0.019)	0.038 (0.022 *)	0.046 (0.021 *)	0.046 (0.022 *)	0.040 (0.022 *)
Auto air conditioner	0.096 (0.016 **)	0.096 (0.016 **)	0.113 (0.016 **)	0.118 (0.017 **)	0.104 (0.021 **)
Anti-lock brake	0.059 (0.021 **)	0.056 (0.018 **)	0.094 (0.015 **)	0.080 (0.019 **)	0.118 (0.018 **)
4WS	0.106 (0.018 **)	0.063 (0.020 **)	0.061 (0.024 **)	0.046 (0.024 *)	0.057 (0.029 *)
Air bags	0.111 (0.023 **)	0.046 (0.019 **)	0.039 (0.013 **)	0.058 (0.015 **)	0.060 (0.013 **)
Sunroof	0.066 (0.021 **)	0.078 (0.018 **)	0.065 (0.019 **)	0.029 (0.018 *)	0.031 (0.018 *)
Car navigation	0.016 (0.066)	0.200 (0.059 **)	0.122 (0.056 *)	0.131 (0.030 **)	0.124 (0.024 **)
Hatchback	-0.088 (0.018 **)	-0.097 (0.016 **)	-0.093 (0.020 **)	-0.064 (0.019 **)	-0.085 (0.020 **)
Coupe	0.112 (0.024 **)	0.060 (0.022 **)	0.057 (0.022 **)	0.052 (0.023 *)	0.036 (0.022 *)
Hardtop	0.039 (0.016 **)	0.017 (0.016)	0.044 (0.014 **)	0.043 (0.015 **)	0.033 (0.014 **)
Station wagon	0.031 (0.023)	0.025 (0.022)	0.049 (0.021 *)	0.075 (0.020 **)	0.058 (0.020 **)
Minivan	0.101 (0.077)	0.099 (0.062)	0.077 (0.061)	0.078 (0.049)	0.145 (0.047 **)
Off-road vehicle	0.293 (0.049 **)	0.151 (0.044 **)	0.164 (0.035 **)	0.127 (0.028 **)	0.176 (0.034 **)
Standard car	0.037 (0.022 **)	0.095 (0.021 **)	0.088 (0.019 **)	0.086 (0.017 **)	0.064 (0.016 **)
Midget car	-0.040 (0.024)	-0.025 (0.025)	-0.036 (0.028)	-0.036 (0.027)	-0.070 (0.027 **)
Diesel	0.125 (0.029 **)	0.116 (0.031 **)	0.087 (0.030 **)	0.210 (0.025 **)	0.177 (0.031 **)
V8 gasoline-fueled	0.111 (0.038 *)	0.100 (0.044 *)	0.131 (0.040 **)	0.200 (0.034 **)	0.218 (0.033 **)
V6 gasoline-fueled	0.079 (0.023 *)	0.032 (0.020)	0.024 (0.019)	0.067 (0.018 **)	0.070 (0.018 **)
Rotary	0.147 (0.071)	0.163 (0.035 **)	0.157 (0.044 **)	0.188 (0.046 **)	0.208 (0.046 **)
4-speed automatic	0.087 (0.013 **)	0.099 (0.012 **)	0.115 (0.012 **)	0.095 (0.013 **)	0.104 (0.012 **)
4-speed floor	-0.183 (0.036 **)	-0.211 (0.032 **)	-0.231 (0.085 **)	-0.247 (0.047 **)	-0.271 (0.037 **)
FF	-0.038 (0.018)	-0.042 (0.018 *)	-0.077 (0.018 **)	-0.062 (0.019 **)	-0.098 (0.018 **)
4WD	0.081 (0.018 **)	0.092 (0.019 **)	0.084 (0.021 **)	0.060 (0.021 **)	0.025 (0.022)
Nissan	0.034 (0.018 *)	0.037 (0.017 *)	0.053 (0.016 **)	0.051 (0.017 **)	-0.010 (0.015)
Mitsubishi	0.029 (0.022)	0.023 (0.021)	0.001 (0.021)	-0.016 (0.020)	-0.002 (0.021)
Mazda	0.027 (0.018 *)	0.028 (0.022)	0.020 (0.020)	-0.025 (0.021)	-0.010 (0.020)
Honda	-0.006 (0.018)	0.003 (0.019)	0.001 (0.024)	0.017 (0.020)	-0.014 (0.019)
Isuzu	0.047 (0.033)	0.050 (0.024 *)	0.048 (0.028 *)	-0.031 (0.029)	-0.031 (0.026)
Fuji	-0.037 (0.022)	-0.060 (0.024 **)	-0.039 (0.024 *)	-0.017 (0.020)	-0.015 (0.021)
Daihatsu	-0.034 (0.026)	0.003 (0.023)	0.010 (0.025)	-0.017 (0.026)	-0.020 (0.024)
Suzuki	0.028 (0.029)	0.035 (0.030)	-0.025 (0.035)	-0.045 (0.031)	-0.014 (0.038)
Adjusted R^2	0.941	0.941	0.938	0.945	0.939
SSR	5.377	5.672	6.052	5.546	5.456
Number of sample	471	486	499	501	492

Note: White's (1980) heteroskedasticity-robust standard errors in parentheses, because the presence of heteroskedasticity is judged by Breusch-Pagan (1979) test; ** and * indicate statistical significance at the 1 and 5 % level, respectively.

and statistically significant parameters. This observation is consistent with the technological difference between FF cars and conventional cars (FR). In fact, production costs for FF are lower than that for FR, because they have no crankshaft.[26] (5) The parameters for 4WD dummy have been falling, and, as a result, the relatively high prices of 4WD vehicles are coming down to a more affordable level.

Finally, the estimated parameters for automaker dummies are positive and statistically significant for Nissan and Isuzu, and negative and statistically significant for Fuji Heavy Industry between 1990-93; but others are small in value and statistically insignificant. Particularly, between 1993-94, all parameters except for Suzuki are becoming statistically insignificant. These results indicate that the list prices for automobiles do not exhibit any significant differences among Japanese automakers recently.

2. *Stability of estimated parameters*

As pointed out in Section II, the problem of a bias may arise due to year-to-year and automaker-to-automaker differences in sample selection criteria. In fact, the above estimations indicate that the 1-year estimations show less stable movement through the sample period than do 2-year estimations.

The stability of estimated parameters is ascertained by the following steps. First, using the full sample and 1-year sample estimations, the null hypothesis with respect to the stability of estimated parameters throughout the sample period are rejected: the *F*-test yields a test value of 1.57 which is greater than the critical value of 1.22 at the 5 % level. Second, using the 2-year and 1-year sample estimations, to the contrary, the null hypothesis regarding the stability of estimated parameters are not rejected: the *F*-test yields the test values of 0.8-1.0 which is less than the critical value of around 1.45 at the 5 % level for each test.[27]

To sum up, stability of parameters do not be rejected within two years, although it is rejected throughout five years from 1990 to 1994. In this sense, the 2-year estimation is the most appropriate result, because it maintains the fundamental conditions behind the supply and demand for automobiles stable. Therefore, the rest of the paper focuses mainly on the estimations based on the 2-year data set.

3. *Hedonic price indexes*

Table 7 presents the estimated quality-adjusted price index (the hedonic price index) for automobiles, which is derived from the above regressions.[28] The hedonic price

[26] FF cars are cost effective because they eliminate a crankshaft which is necessary for FR cars.

[27] The critical values are different across the sample periods, because the number of samples is different in each year. The degree of freedom is therefore also different.

[28] The general method for deriving a quality-adjusted price index (a hedonic price index) from an estimated hedonic function is the exponential transformation of the estimated parameter for year dummy variable. See Appendix C in Shiratsuka (1995) for details.

indexes dropped 0.1-0.4 % annually while the average price of the data set rose 4 % and the CPI (after adjustments for the consumption tax rate changes) rose 0.6 %, both annually.

The above results show that quality changes in automobiles have significantly affected the accuracy of the CPI. The differences in rate of change from the previous year between the CPI and the hedonic price indexes (based on the 2-year sample and full sample estimations) are two to three times greater than the standard errors of the estimated parameters for year dummies (shown in brackets in Table 7).

In terms of year-to-year movements, the hedonic price index fell slightly in 1991, and then rose in 1992 before falling sharply again in 1993-94. This is consistent with the following observations in the Japanese automobile market. First, in 1992, automobile prices, particularly those of business cars, rose because of an increase in steel prices; the hedonic price index indicates that automobile prices also rose after quality adjustments. Second, low priced automobiles were introduced after 1993, and it is clearly visible in the hedonic price index, although this is not reflected in the CPI.

Although there are some differences in the movements of the price indexes based on the estimations for various data sets, the difference in the rate of change between the full sample and 2-year sample price indexes is less than twice of the standard errors of the estimated parameters for year dummies, which is shown in brackets for the 2-year estimations. The 1-year price index, however, exhibits different movements from those of the full sample and 2-year sample price indexes, reflecting the instability of the

Table 7
Hedonic Price Indexes

	1990	1991	1992	1993	1994	Annual	Cumulative
Full sample	100.0	99.7	101.2	99.9	98.9		
		(-0.3)	(1.5)	(-1.3)	(-1.0)	(-0.276)	(-1.100)
2-year sample	100.0	99.3	100.6	99.2	98.5		
		(-0.7)	(1.3)	(-1.4)	(-0.7)	(-0.377)	(-1.500)
		[0.007]	[0.007]	[0.007]	[0.007]		
1-year sample	100.0	99.3	100.9	98.8	99.5		
		(-0.7)	(1.6)	(-2.1)	(-0.7)	(-0.125)	(-0.500)
Average prices	100.0	107.7	112.8	114.3	117.1		
		(7.7)	(4.7)	(1.3)	(2.4)	(4.025)	(17.100)
CPI	100.0	100.5	101.2	101.8	102.6		
		(0.5)	(0.7)	(0.6)	(0.8)	(0.644)	(2.600)

Note: Percent changes from previous year in parentheses; standard errors for estimated parameters for year dummies in brackets; CPI is adjusted for the consumption tax rate changes.

estimated parameters. In particular, the difference in the rate of change in 1994 between the 1-year and other price indexes is more than twice the size of the standard error. Therefore, the 1-year hedonic price index seems to suffer considerably from the sampling bias, which has been discussed earlier.

4. *Upward bias in the CPI*

Now I examine how much upward bias was caused by the failure in quality adjustment for the official CPI. Here, I estimate the impact of including the hedonic price index estimated above, instead of the CPI for automobiles, on the overall and durable goods CPI.[29] Table 8 presents the estimations. It indicates that the inclusion of the hedonic price index reduces the overall CPI by 0.01 % per year and the durable goods CPI by 0.2 % between 1990-94.

The above figures are nearly equal to the estimations for personal computer prices in Shiratsuka (1995). Although quality changes for automobiles are less than those for personal computers, their impact on the CPI is approximately the same because the weight of automobiles in the CPI is far greater than that for personal computers.

The price reducing impact of quality changes in automobiles expanded between 1993-94; and it is estimated to have reduced the overall CPI by 0.01-0.02 % per year and the durable goods CPI by 0.3-0.6 %. This increase in price reducing impact is due to the combination of the recent rise in the CPI and the decline in the quality-adjusted price index for automobiles.

C. Results of Estimation by Size and Styling

Next, I estimate and compare the hedonic price indexes for different sizes and

Table 8
Impact of Inclusion of Hedonic Price Index to CPI

(%)

	1991	1992	1993	1994	Annual	Cumulative
The overall CPI (Tokyo)						
Full sample estimation	-0.009	0.009	-0.021	-0.020	-0.011	-0.043
2-year sample estimation	-0.014	0.007	-0.022	-0.017	-0.012	-0.047
The durables CPI (Tokyo)						
Full sample estimation	-0.181	0.183	-0.425	-0.404	-0.208	-0.837
2-year sample estimation	-0.272	0.139	-0.449	-0.337	-0.231	-0.928

[29] As explained in section II, the car prices, which are the dependent variable of the hedonic function, are the listed retail prices (excluding taxes and registration fees) in the Tokyo area in October. Accordingly the CPI data used for comparison are the CPI in Tokyo in October, which is adjusted for the consumption tax rate changes (from 6 to 4.5 % in April 1991, and from 4.5 to 3 % in April 1994; excluding mini cars).

stylings of automobiles.

Since automobiles of various sizes and stylings have very different characteristics (see Appendix 2), the quality-adjusted price indexes for the automobiles in various sizes and stylings are likely to move differently.[30] However, the current CPI does not cover standard cars, number of items surveyed for automobiles are too limited to take full account of a difference in price movement among the various stylings.

In spite of the argument that the 2-year data set is appropriate to balance the effects of changes in the supply and demand fundamentals against the leveling requirement of the samples, I use the full sample period data set for the estimation below for the following reasons. First, I try to secure large sample size in various classifications for the estimation of hedonic functions to cover as wide a range of automobiles as possible. Second, the use of full sample period data for estimation does not seem to cause any serious problems, because the difference between the estimated hedonic price indexes for the full sample and the 2-year sample data is within a permissible range, and they both have similar trends in the same direction.

1. Estimation by size

Table 9 presents the estimated hedonic functions for various sizes of automobiles: standard, small, and mini cars. The hedonic function for small cars has a smaller constant and generally larger parameters for performance characteristics as well as dummies than those for standard cars. The parameters have the same signs except for automaker dummies. On the other hand, the hedonic function for mini cars displays slightly different results; in particular, it has negative signs for wheelbase and interior space. This result is not surprising, because the main feature of mini cars is their compactness. Thus, the various measures of size such as wheelbase and interior space may not positively contribute to their prices.

The *F*-test rejects the null hypothesis that the parameters are identical across the three stylings of automobiles: the *F*-value is 9.07 which is larger than the critical value of 1.34 at the 5 % level of significance.

From the above estimated hedonic functions, the hedonic price indexes are derived for the three stylings of automobiles in Figure 2. It shows that the prices moved quite differently across the three stylings. The prices of standard cars, which are not included in the CPI, rose in 1991 but stabilized by 1992, and then they fell significantly in 1993-94. The prices of small and mini cars moved slightly differently in 1991, but they moved almost parallel since then.

The hedonic price index for standard cars rose faster between 1990-91 and also fell more quickly between 1993-94 than the indexes for small and mini cars. Therefore,

[30] Appendix 2 compares the averages and standard deviations of the principal components of characteristics among the various sizes and stylings of cars; it shows that they differ.

Table 9
Estimation by Size

	Standard car		Small car		Mini car	
Constant	6.660	(0.084 **)	5.661	(0.086 **)	8.575	(1.012 **)
Max power	0.273	(0.014 **)	0.401	(0.014 **)	1.385	(0.070 **)
Wheelbase	0.157	(0.032 **)	0.365	(0.041 **)	-0.760	(0.415 *)
Interior space	0.044	(0.011 **)	0.073	(0.011 **)	-0.287	(0.129 *)
Air conditioner	0.032	(0.023)	0.039	(0.011 **)	0.059	(0.013 **)
Auto air conditioner	0.061	(0.016 **)	0.113	(0.008 **)		
Anti-lock brake	0.109	(0.010 **)	0.092	(0.013 **)	0.089	(0.018 **)
4WS	0.020	(0.015)	0.105	(0.012 **)	0.084	(0.044 *)
Air bag	0.063	(0.009 **)	0.053	(0.014 **)	0.075	(0.028 **)
Sunroof	0.019	(0.013)	0.102	(0.013 **)	0.123	(0.024 **)
Car navigation	0.117	(0.026 **)				
Hatchback	-0.033	(0.038)	-0.081	(0.009 **)		
Coupe	0.062	(0.015 **)	0.079	(0.014 **)		
Hardtop	0.043	(0.010 **)	0.031	(0.008 **)		
Station wagon	0.036	(0.027)	0.050	(0.011 **)	0.188	(0.049 **)
Minivan	0.075	(0.040 *)	0.087	(0.040 *)	-0.363	(0.227)
Off-road vehicle	0.166	(0.023 **)	0.101	(0.027 **)		
Diesel	0.080	(0.018 **)	0.146	(0.017 **)		
V8 gasoline-fueled	0.240	(0.020 **)				
V6 gasoline-fueled	0.088	(0.012 **)	0.044	(0.013 **)		
Rotary	0.260	(0.030 **)	0.067	(0.061)		
4-speed automatic			0.095	(0.007 **)	0.104	(0.013 **)
4-speed floor	0.097	(0.011 **)	-0.212	(0.029 **)	-0.115	(0.022 **)
FF	-0.122	(0.013 **)	-0.035	(0.013 **)		
4WD	0.053	(0.015 **)	0.094	(0.014 **)	0.068	(0.011 **)
Nissan	0.017	(0.012)	0.038	(0.010 **)		
Mitsubishi	-0.025	(0.015 *)	0.002	(0.013)		
Mazda	-0.059	(0.016 **)	0.025	(0.011 *)	-0.145	(0.049 **)
Honda	0.035	(0.018 *)	-0.023	(0.011 *)	-0.016	(0.068)
Isuzu	-0.034	(0.022)	0.029	(0.016 *)		
Fuji	-0.048	(0.024 *)	-0.015	(0.011)	-0.184	(0.043 **)
Daihatsu	-0.062	(0.037 *)	-0.010	(0.014)	-0.133	(0.046 **)
Suzuki			0.053	(0.024 *)	-0.097	(0.048 *)
1991	0.010	(0.015)	-0.015	(0.009 *)	0.000	(0.015)
1992	0.010	(0.015)	-0.001	(0.009)	0.011	(0.018)
1993	-0.001	(0.014)	-0.014	(0.010)	0.000	(0.016)
1994	-0.022	(0.014)	-0.016	(0.011)	0.008	(0.018)
Adjusted R^2	0.864		0.875		0.758	
SSR	8.731		14.862		1.857	
Number of sample	825		1,337		287	

Note: White's (1980) heteroskedasticity-robust standard errors in parentheses, because the presence of heteroskedasticity is judged by Breusch-Pagan (1979) test; ** and * indicate statistical significance at the 1 and 5 % level, respectively.

Figure 2
Hedonic Price Indexes by Size

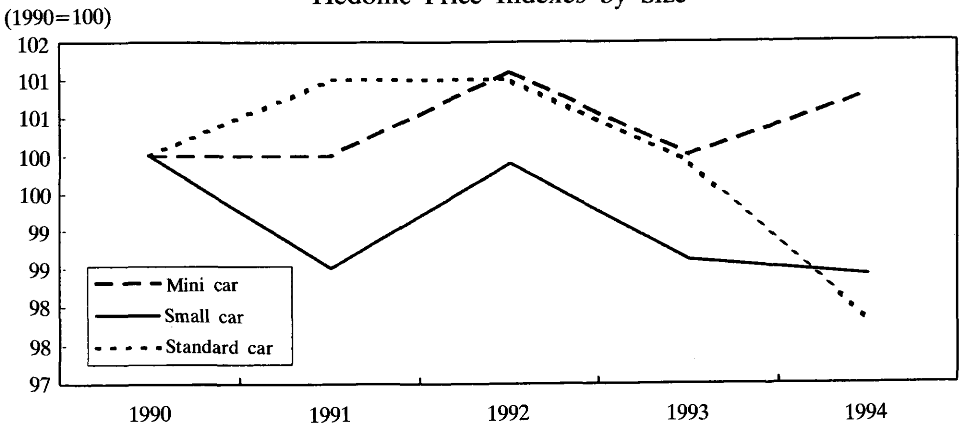
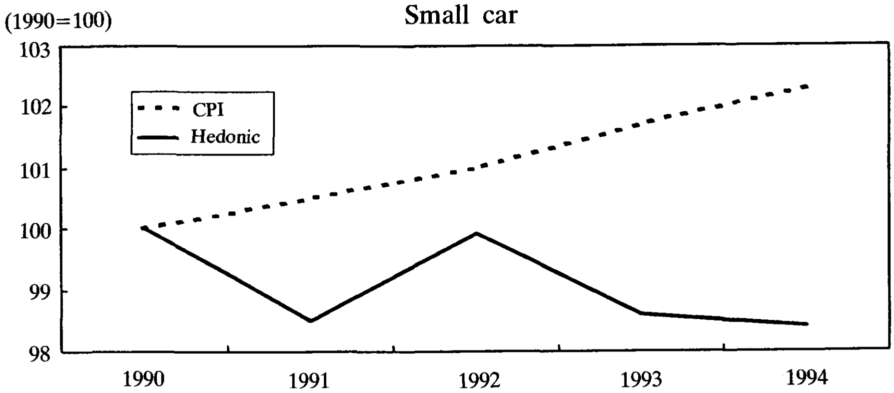
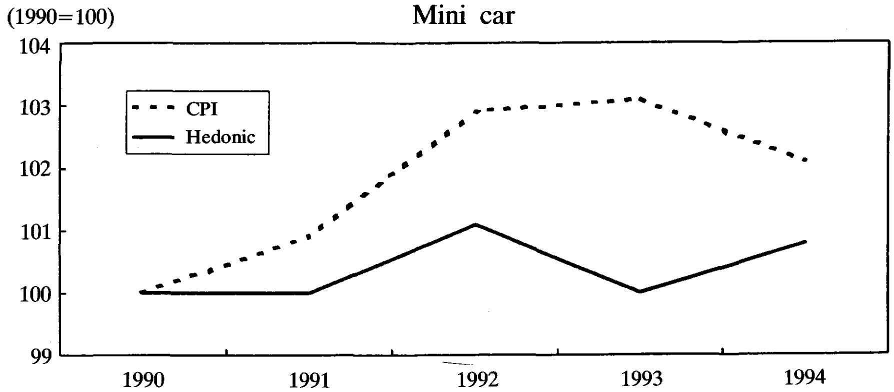


Figure 3
Comparison of Hedonic Price Indexes and CPIs by Sizes

Small car



Mini car



excluding standard cars from the CPI basket, the CPI is likely to have produced a downward bias between 1990-91 and an upward bias between 1993-94. In particular, the CPI failed to capture the recent fall in automobile prices as the drop in the prices of standard cars in 1994.

Figure 3 compares the hedonic price indexes for small and mini cars with the corresponding CPIs. It indicates that the CPIs produce a substantial upward bias, because the hedonic price indexes are much lower.

2. *Estimation by styling*

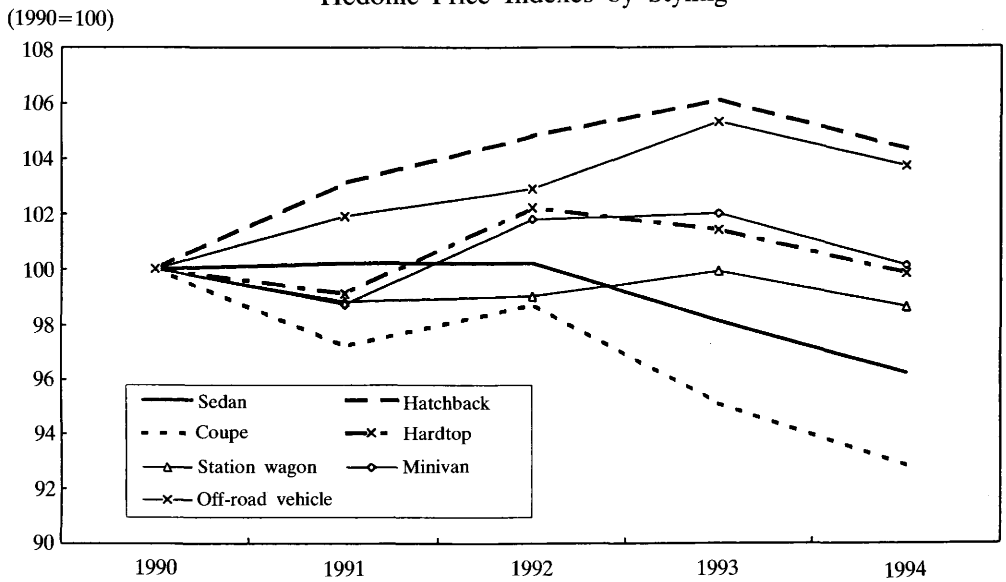
Next, the hedonic price functions are estimated for the different stylings of standard and small cars, such as sedans, hatchbacks, and coupes. Although the detailed results are omitted due to considerations of space, the estimation performance deteriorates slightly. For example, the hedonic price functions have negative and statistically significant parameters for wheelbase of hatchbacks and interior space of coupes. Furthermore, estimated parameters for interior space of station wagons, for wheelbase of minivans and off-road vehicles are statistically insignificant. This may be because sample variations have become smaller as a result of samples with similar characteristics being grouped together. In fact, the standard deviations of the parameters of characteristics are substantially smaller for the sedan, hatchback, coupe, and hardtop.[31] Thus, some caution is needed when interpreting the estimations. A bias in estimations is likely to be greater in the present case. The *F*-test rejects the null hypothesis that the estimated parameters are stable through the whole sample period at the 5 % level: the *F*-value is 6.50 which is greater than the critical value of 1.21 at the 5 % level.

Figure 4 shows the time-series movements of hedonic price indexes for the seven different stylings of automobiles. Although all seven stylings exhibited declines between 1993-94, there are substantial differences. The hedonic price indexes for hatchbacks and off-road vehicles moved up between 1990-93, while those for sedans and coupes moved down in 1993: the hedonic price indexes for station wagons, hardtops, and minivans remained stable during the same period.

The above observations indicate that it is important to consider the difference in price movements across various stylings of automobiles to construct a reliable price index. However, details of the CPI samples are not made public, although the selection is reported to take new car registration data into account. Even an automobile with the same name has many models: for example, the Corolla has various models ranging from a family-type sedan to a sports-type coupe.

[31]The standard deviation of the parameter for interior space (measured in unit of m^3) is 0.972 for standard and small cars, but only 0.199 for sedans, 0.183 for hatchbacks, 0.392 for coupes, and 0.231 for hardtops.

Figure 4
Hedonic Price Indexes by Styling



3. *Estimation by size and styling*

Estimation of the hedonic functions and its price indexes for different sizes and stylings are conducted. As expected, the estimation performance deteriorates because the samples by styling are further divided by size into smaller subsamples. Therefore, caution is also needed when interpreting this estimation.[32]

Table 10 presents the results of the *F*-test for the stability of the estimated parameters. The top row under automobile stylings lists the test results for the null hypothesis that parameters are identical between standard and small cars in each styling. The null hypothesis is rejected for the sedan, coupe, hardtop, and minivan at the 1 % level and for the off-road and station wagon at the 5 % level. Therefore, parameters of the hedonic functions are found to be statistically different between standard and small cars in all stylings.

The middle (bottom) row list the *F*-test results for the stability of estimated parameters for standard (small) cars across different stylings. In the case of standard cars, they generally reject the identity of estimated parameters across different stylings. In the case of small cars, they also tend to produce similar results; but the stability of the parameters cannot be rejected even at the 10 % level between the sedan and hardtop, the station wagon and off-road vehicle, and the minivan and off-road vehicle. This seems to

[32]The test excludes the hatchback standard cars because their samples are limited.

Table 10
F-test for the Estimation by Size and Styling

	Sedan	Hatch-back	Coupe	Hardtop	Station wagon	Minivan	Off-road vehicle
Standard vs Small	⊙	—	⊙	⊙	○	⊙	○
Standard car							
Sedan	—	—	⊙	⊙	⊙	○	⊙
Hatchback	—	—	—	—	—	—	—
Coupe	⊙	—	—	⊙	⊙	X	⊙
Hardtop	⊙	—	⊙	—	⊙	⊙	⊙
Station wagon	⊙	—	⊙	⊙	—	○	⊙
Minivan	○	—	X	⊙	○	—	⊙
Off-road vehicle	⊙	—	⊙	⊙	⊙	⊙	—
Small car							
Sedan	—	⊙	⊙	X	⊙	⊙	⊙
Hatchback	⊙	—	⊙	⊙	⊙	⊙	⊙
Coupe	⊙	⊙	—	⊙	⊙	⊙	△
Hardtop	X	⊙	⊙	—	⊙	⊙	○
Station wagon	⊙	⊙	⊙	⊙	—	⊙	X
Minivan	⊙	⊙	⊙	⊙	⊙	—	X
Off-road vehicle	⊙	⊙	△	○	X	X	—

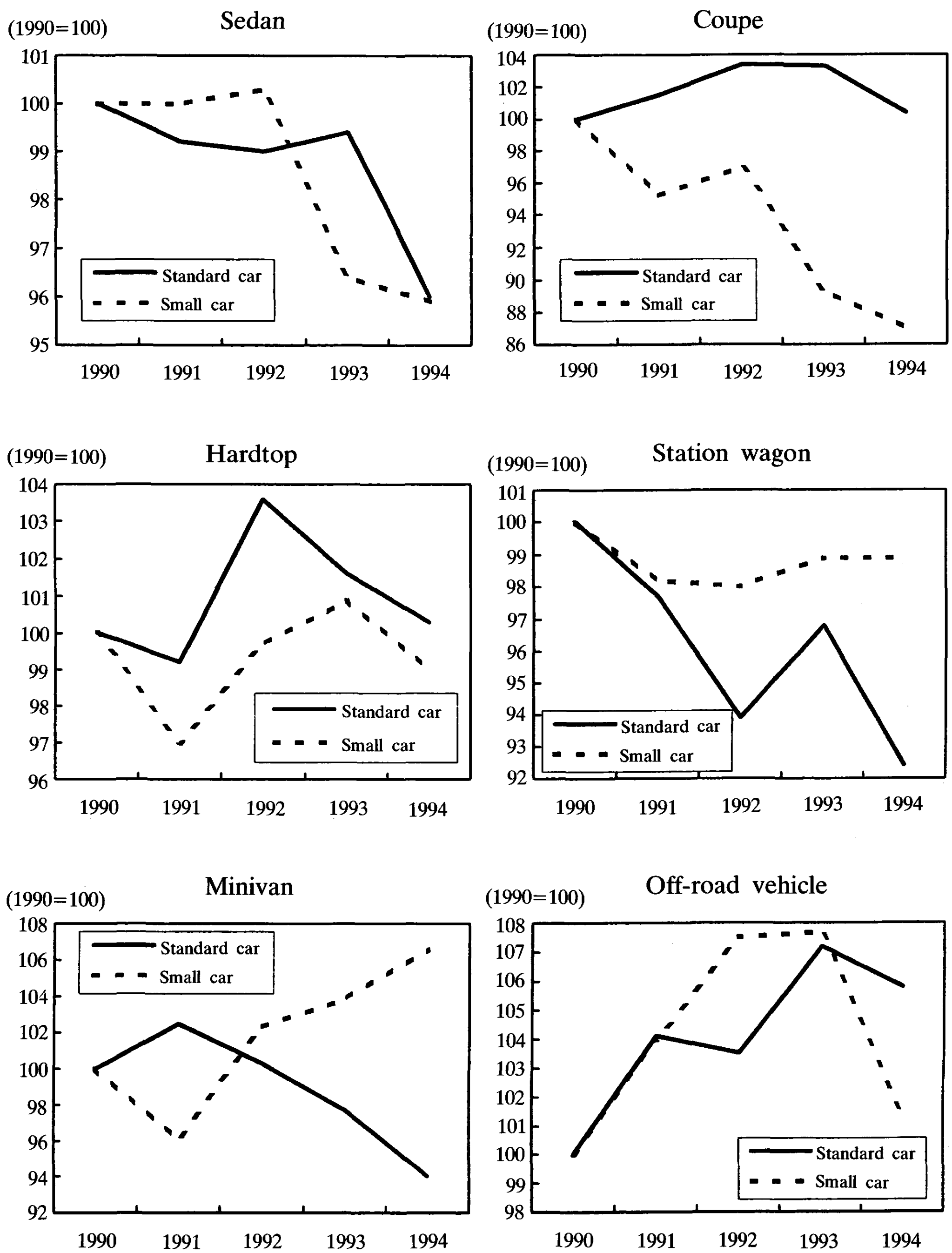
Note: Symbols in the table are defined as follows: ⊙ indicates significant at 1%, ○ at 5%, △ at 10%, and X indicates insignificant.

be reasonable. For example, comparing between the sedan and hardtop models of Nissan Bluebird, differences in their characteristics appear to be small. Likewise, the test results suggest that differences in characteristics of RV-type vehicles in the category of small cars are negligible.

Figure 5 plots the hedonic price indexes for different sizes of the same styling of automobiles, which are derived from the estimated hedonic functions. They generally exhibit very different movements in direction and magnitude. For example, the price index for the coupe of standard cars rose relative to that of small cars; the price index for the station wagon and minivan of standard cars fell relative to that of small cars. Exceptions are sedan and hardtop, and their price movements are relatively similar between standard and small cars.

These results indicate that different sizes and stylings of automobiles exhibit not only different characteristics, but also different price movements. This conclusion suggests

Figure 5
Hedonic Price Indexes by Size and Styling



that the problems of limited sampling and coverage (such as the exclusion of standard cars) in the CPI have produced significant bias. This problem of bias may have become particularly serious in recent years because of the diversified consumer preference for RV-type vehicles such as station wagons and off-road vehicles as well as increased demand for larger luxury automobiles.

Some caution, however, is needed when interpreting the above results, because they suffer from a reduced degree of freedom and increased instability with respect to the estimated parameters due to more subdivided samples. Therefore, the interpretation should be limited to qualitative not quantitative assessment. To evaluate more accurately the magnitude of the upward bias in the CPI, additional studies will be necessary such as estimating the hedonic functions for each size and styling of automobile with different characteristics as explanatory variables.

IV. Hedonic Price Indexes for Individual Automobile Models

This section discusses the problem of quality adjustment methods for the CPI from another point of view. First, it discusses basic problems with the current method of quality adjustments for the CPI. Second, it presents a practical method to apply the hedonic approach to specification changes in conventional price indexes.[33,34] Third, it examines the extent of a possible bias in the CPI through the simulation which compares differences in the evaluation of quality changes between the CPI methods and the hedonic approach.[35]

A. Method of Quality Adjustments at Specification Change

Before discussing the problem of quality changes for the CPI, two methods for quality adjustment that are mainly used at specification changes in the CPI: namely the "direct comparison method" and the "price link method."[36]

As a price index is supposed to represent a price change of a product while keeping its quality constant, its rate of change should be equal to the rate of change in product price minus the rate of a quality change: that is,

$$\Delta\ (\text{Price Index}) = \Delta\ (\text{Product Price}) - \Delta\ (\text{Quality})$$

where $\Delta\ (\bullet)$ represents the rate of change in the variable in parentheses. This relation-

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[33]The Bank of Japan Price Index Study Group (1992) discussed methodology of specification changes.

[34]The present method of incorporating the hedonic approach to the conventional price index is essentially the same as that proposed in Ohta (1980).

[35]The method applied to the CPI in this paper can be applied to other price indexes (such as the WPI) that are based on a fixed set of product models.

[36]In addition to the direct link method and the price link method, a third method that makes an adjustment for difference in quantity of a product is sometimes used.

ship is useful for explaining the above two methods.

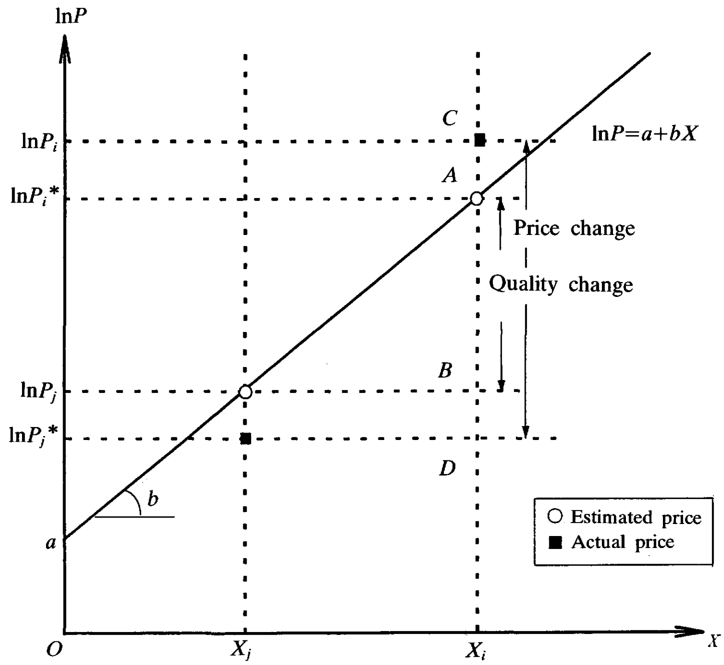
In the direct comparison method, the rate of change in a price index is the same as that in nominal prices between an existing product and a new product, or it assumes no quality change between them. In the price link method, the rate of change in a price index is zero, or it assumes that the price change between an existing product and a new product fully reflects the change in quality. However, both methods are not that realistic: in the real world, there might be quality changes, and such changes might be equivalent to neither zero nor nominal price changes.

As a result, it is apparent that the CPI does not fully account for actual quality changes. Therefore, the quality adjustment methods in specification changes are a most likely source of measurement errors in the official CPI.

B. Application of the Hedonic Approach to Specification Chang

Next, I present a practical method for constructing a reliable CPI by adjusting quality changes with the hedonic approach. This method is something of a compromise between the following two requirements. On one hand, it is necessary to employ the hedonic approach to account for quality changes more adequately. On the other hand, it

Figure 6
Application of the Hedonic Approach to Specification Change



is also necessary to sustain the conventional methodology of surveying specific prices every month. Thus, it is not appropriate to use the anti-logarithm of the estimated parameter for the year dummy as a quality-adjusted price index.

Figure 6 describes the method for applying the hedonic approach to specification changes in the case of one performance characteristic. The x-axis measures the characteristic, and the y-axis the logarithm of the product price. The hedonic function is represented by a straight line with a constant (a) and a slope (b). Let X_i and X_j represent the characteristic values of the exiting and new products, respectively. Then the theoretical price (that is, the estimated price based on the hedonic function) is given by the anti-logarithm of $\ln P = a + bX$. The quality change between the existing product and the new product is measured by the difference in the theoretical prices between the existing product and the new product, which is depicted by AB in Figure 6. Let ■ represent the observed product price in Figure 6. Then, CD measures the change in the product price. Therefore, the difference between CD and AB corresponds to the change in the quality-adjusted price index. In this particular example, the quality-adjusted price index rises with an introduction of the new product because CD > AB.

With this methodology, the following relationships hold among rates of change in terms of product price, quality, and the quality-adjusted price index.

$$\Delta \text{ (Product Price)} > \Delta \text{ (Quality)} \longrightarrow \Delta \text{ (Price Index)} > 0$$

$$\Delta \text{ (Product Price)} = \Delta \text{ (Quality)} \longrightarrow \Delta \text{ (Price Index)} = 0$$

$$\Delta \text{ (Product Price)} < \Delta \text{ (Quality)} \longrightarrow \Delta \text{ (Price Index)} < 0$$

C. Simulation of Specification Changes

Failure in quality adjustments often creates a bias in the CPI. In order to check the accuracy of quality adjustment method in the CPI, a simulation of specification changes was conducted by applying the aforementioned framework for quality adjustment. Some thirteen Toyota and Nissan models were selected as simulation samples, because they are the most representative and continuous through the whole sample period (1990-1994). They are evaluated by the estimated hedonic functions based on the 2-year sample data.[37,38]

[37]At present, models surveyed in the CPI are not made public. However, in the past, models surveyed in the CPI appear to have been made public, because Ohta (1980) actually used such models for checking the accuracy of the quality adjustment method for the official CPI.

[38]Simulation used the hedonic function based on the 2-year sample data to evaluate quality changes in each model. This is because the 2-year sample estimation maintains fundamental conditions behind the supply and demand for automobiles stable while minimizing the effects of a bias in the sample structure. Ideally, to measure quality changes most accurately, a hedonic function should be estimated for each size and styling of automobiles because the characteristics differ substantially across different sizes and stylings. Therefore, further studies will be needed before the hedonic approach is applied to the official CPI.

Table 11
Simulation for Specification Changes

		1991	1992	1993	1994
Carolla	Product price	20.5	0.0	1.4	0.7
	Quality	17.3	0.0	0.0	0.0
	Quality-adjusted price	3.2	0.0	1.4	0.7
Carina	Product price	0.0	-9.5	0.0	9.1
	Quality	0.0	-15.6	0.0	14.3
	Quality-adjusted price	0.0	6.1	0.0	-5.2
Corona	Product price	0.0	8.6	0.0	0.9
	Quality	0.0	18.0	0.0	0.0
	Quality-adjusted price	0.0	-9.5	0.0	0.9
Camry	Product price	0.0	11.9	0.0	-4.0
	Quality	0.0	9.7	0.0	-4.3
	Quality-adjusted price	0.0	2.2	0.0	0.3
Mark II	Product price	0.0	0.0	10.4	2.6
	Quality	0.0	0.0	50.9	-6.2
	Quality-adjusted price	0.0	0.0	-40.5	8.8
Crown	Product price	7.8	0.0	1.8	0.0
	Quality	14.1	0.0	-1.0	0.0
	Quality-adjusted price	-6.3	0.0	2.8	0.0
Celsior	Product price	0.0	5.3	0.2	0.7
	Quality	0.0	0.0	0.0	2.5
	Quality-adjusted price	0.0	5.3	0.2	-1.8
Sunny	Product price	3.0	2.9	5.9	-4.4
	Quality	0.0	0.0	21.8	-16.5
	Quality-adjusted price	3.0	2.9	-15.9	12.1
Primera	Product price	3.0	4.7	0.8	1.7
	Quality	9.8	9.7	0.0	5.0
	Quality-adjusted price	-6.8	-5.0	0.8	-3.3
Bluebird	Product price	1.3	0.8	1.8	4.1
	Quality	9.2	-8.9	0.0	11.3
	Quality-adjusted price	-7.9	9.7	1.8	-7.1
Skyline	Product price	11.6	0.0	-1.9	14.0
	Quality	9.7	0.0	15.1	23.0
	Quality-adjusted price	1.9	0.0	-17.0	-9.0
Cedric	Product price	13.8	0.0	5.8	0.0
	Quality	27.1	-11.0	12.1	0.0
	Quality-adjusted price	-13.3	11.0	-6.3	0.0
Cima	Product price	0.0	-0.7	9.5	0.0
	Quality	-7.0	-8.7	24.2	0.0
	Quality-adjusted price	7.0	7.9	-14.6	0.0
Inadequate quality adjustment case		7	7	6	7
Increase in quality-adjusted price		3	5	1	2
Decrease in quality-adjusted price		4	2	5	5
Standard errors for hedonic price index		0.7	0.7	0.7	0.7

The results of the simulation are summarized in Table 11. And the rate of changes in product prices, qualities, and quality-adjusted price indexes are also indicated in this Table.[39] The results suggest that quality changes are likely to have caused a bias in the CPI. Toyota Corolla models, for example, changed between 1990-91 and product prices rose 20.5 %. However, as the quality change computed by the hedonic function increased 17.1 %, it follows that the quality-adjusted price index rose only 3.4 % (20.5 % minus 17.1 %).

In the total of 52 simulation samples (13 automobiles × 4 years), 28 cases are deemed to have some quality changes. Among these 28 cases, it is only Toyota Camry in 1994 that the rate of change in the quality-adjusted price index is less than the two times of standard deviations. Therefore, the other 27 case have experienced a statistically significant change in the quality-adjusted price index. An increase in the quality-adjusted price index is found in 11 cases and a decrease in 16 cases.

The above simulation used relatively continuous models to ensure consistency in terms of size and styling of the simulation samples. In practice, however, the construction of a price index is faced with product diversification in terms of sizes and stylings such as an increase in the number of standard and RV-type vehicles in the market. In such cases, the present construction methodology of the CPI is less than appropriate and a bias is likely to exist. Moreover, because quality changes are not properly taken into account, there is a high possibility that a specification change in the sample structure may miss the best timing.

The hedonic approach, of course, is not perfect. In particular, there is a potential problem of "omitted characteristics" since it evaluates quality changes in terms of a specified bundle of performance characteristics. For example, the hedonic approach may create a bias if sizes and stylings are vastly different. Nevertheless, it should be possible to deal with this problem by estimating a hedonic function with a sample set of similar stylings and sizes. These are some of the topics for future research if the hedonic approach is to be applied to quality adjustment for the official CPI.

V. Conclusion

This paper has provided empirical evidence showing why the Japanese CPI has failed to account for quality changes in automobiles. It has employed the hedonic approach to establish the quality-adjusted price index, and examined the upward bias caused by the failure in taking account of the quality changes in automobiles. The major results are summarized as follows:

① The estimated hedonic function implies that, between 1990-94, the quality-adjusted

[39]If model changes do not produce any changes in the explanatory variables of characteristics in the hedonic function, the hedonic approach implies no quality changes. Therefore, it is important to keep in mind that the absence of quality changes does not necessarily mean no model changes.

price index for automobiles declined 0.3 % annually, while the CPI (after adjustments for consumption tax rate changes) rose 0.6 % annually. As a result, the overall CPI is biased upward by 0.01 % per year. Moreover, the durable goods CPI is biased upward by 0.2 %, reflecting heavy weight of automobiles among consumer durables. In addition, the tendency is on the rise in recent years: it is estimated to have been around 0.3-0.4 % annually for the durable goods CPI and about 0.02 % annually for the overall CPI. This is because the quality-adjusted price index rose between 1991-92, and turned to decline since then.

② The estimates of the hedonic functions for different automobile models indicated that the quality-adjusted price index varied from size to size and from styling to styling. Given the increasing demand for larger luxury automobiles (partly due to tax reductions) and the popularity of RV-type vehicles, the bias in the CPI is likely to have increased in recent years. This is because the CPI covers only a limited range of models, and in particular excludes standard cars.

③ The simulation for specification changes were conducted to compare how precisely the conventional methods and the hedonic method account for the quality changes. The results suggest that the CPI has failed to adjust for quality changes in the specification changes.

These empirical results suggest that the current methodology for constructing the Japanese CPI needs to be revised, at least with respect to the automobiles. This is particularly important because the price index is often used as a barometer of macroeconomic conditions such as inflationary pressure and the state of the business cycle. Moreover, it is used as a deflator in the System of National Accounts to convert nominal values into real values.[40] It is important to increase the accuracy of the price index by minimizing any potential bias.

Based on the findings in this paper, the following measures are worth considering to increase the accuracy of the automobile CPI. First, the CPI basket has to include standard cars. The automobile CPI without standard cars is likely to have a significant bias and, thus, fails to cover the real price changes. This is because demand for larger luxury automobiles has increased (partly because of substantial reductions in the tax on automobiles), and, in response, automakers have increased the supply of large standard cars called "3-number" automobiles. In addition, the estimations imply that the quality-adjusted price index for standard cars declined most sharply in these two years among the three classes of automobiles; standard, small, and mini cars.

Second, the diversification of consumer preferences requires the expansion of coverage for automobiles in the CPI basket. The coverage and sampling should be expanded to cover a variety of sizes and stylings. This is apparent in recent years as the popularity of RV-type vehicles increases. Therefore, to construct a reliable price index, it is neces-

[40]See the Bank of Japan Price Index Study Group (1992) for the function and the use of price indexes.

sary to include as many samples as cost-effectiveness permits.

Third, the hedonic approach should be employed as a quality adjustment method in constructing the CPI. The paper has proved that the hedonic approach can help incorporate the quality changes into the price index even within the conventional methodology, and minimize the possible bias. The hedonic approach is not yet widely used in the construction of official price statistics. There seems to be some concern that adoption of such approach results in more works in data collection, the estimation of hedonic functions, and substantial changes in the process of constructing the price indexes. However, with the method shown in the Section IV, it is possible to incorporate the hedonic approach into the present framework for constructing the CPI.

The method mentioned in Section IV combines the merits of both the hedonic approach and the conventional methodology. As long as no specification changes occur, collecting the observed prices is enough to construct a price index. In addition, once a specification change occurs, the hedonic approach is to be employed to account for quality changes between the existing and new products. This is an attempt to make quality adjustments by using an objective method while minimizing the burden of the statistical data construction. Such method has already partially been applied to construct the WPI for mainframe computers, personal computers, and other related equipment. However, the application of this method is currently limited to a small number of products, and not yet widely used in the construction of the official price indexes in Japan.

Measures for increasing the accuracy of the official price indexes, especially an application of the hedonic approach, need to be more widely discussed in Japan.

Appendix 1. Multicollinearity and the Selection of Explanatory Variables

This appendix discusses the method of selecting explanatory variables for the hedonic function out of many possible characteristics under the existence of multicollinearity among the variables. The diagnostic method of multicollinearity is discussed in Belsley, Kuh and Welsch (1980) and Minotani (1992). Such method is applied to the hedonic analysis of automobile prices by Arguea and Hsiao (1993). Following their analysis, this appendix tries to select some basic performance characteristics as the explanatory variables of a hedonic function out of eleven performance characteristics.

A. Characteristics Variables of Automobiles and Multicollinearity

Before estimating the hedonic function, it is necessary to choose some basic performance characteristics, which explain the automobile prices, out of many possible functional and performance characteristics. The problem here is that these characteristics often exhibit high multicollinearity. While data on the performance characteristics for automobiles are relatively easy to obtain, these performance characteristics tend to exhibit high multicollinearity. Table 3 in the text presents correlation matrix of eleven performance characteristics. It shows high correlation: 0.9 for interior space and seating capacity, and for engine displacement and torque, and 0.7-0.9 for many other pairs. It is not surprising to find a high correlation among length, width, and height of an automobile, as well as wheelbase, interior space, because all of them are indicators for automobile size. Furthermore, it is reasonable that the size of a automobile is related to engine power and fuel efficiency.

High multicollinearity tends to increase the variance of estimated parameters and the instability of the estimated parameters. Table A-1 presents the estimations for the hedonic functions with all performance characteristics as explanatory variables. This result apparently indicates the instability of the estimated parameters through the sample period. Quite few parameters are statistically significant, and their signs are often different from those predicted by theory, as well as sometimes change from year to year. Part of the problem may be due to bias that in the data set. However, the main reason seems to be the high degree of multicollinearity among performance characteristics, because the results with a smaller number of selected explanatory variables do not exhibit instability with respect to different sample period (see Table 6-2 in the text).

There are two standard approaches to deal with multicollinearity. The first approach is to create several principal components that capture common movements among highly correlated performance characteristics and to use them as explanatory variables for hedonic functions. This resolves the problem of multicollinearity because principal components are uncorrelated with each other. The second approach is to reduce the number of performance characteristics into some basic performance characteristics that are likely to be independent of each other and have great explanatory power at the same time. In this approach, it becomes necessary to diagnose multicollinearity structure among characteristics.[41]

In the following, the principal component approach will be first examined. But since it turns out to be lacking, this paper adopts the second approach.

B. Principal Component Approach

The principal component approach is often used when a regression analysis involves many highly correlated variables. This method has the advantage of transforming highly correlated variables into some uncorrelated ones.[42] Using these principal components as explanatory variables, it can resolve the problem of multicollinearity while reducing the number of explanatory variables and increasing the degree of freedom. The method

[41]Another possible approach is a Ridge regression approach. However, there is no consensus among economists about the standard rule of judgment on Ridge regression results; also Ridge regression does not necessarily resolve the problem of multicollinearity. Therefore, the paper does not adopt this approach. See Minotani (1992) and Judge et al. (1985) for discussion of Ridge regression method.

[42]See Honda and Shimada (1977) and Manly (1992) for explanation of principal component analysis.

Table A-1
Estimations with All the Performance Characteristics

	1990	1991	1992	1993	1994
Constant	5.954 (0.393 **)	6.603 (0.376 **)	6.700 (0.366 **)	6.963 (0.377 **)	7.039 (0.375 **)
Length	0.142 (0.050 **)	-0.022 (0.046)	-0.038 (0.042)	0.045 (0.044)	0.080 (0.045 *)
Width	-0.529 (0.200 **)	-0.239 (0.181)	-0.231 (0.196)	-0.201 (0.182)	-0.356 (0.187 *)
Height	0.302 (0.144 *)	0.187 (0.140)	0.191 (0.121)	0.038 (0.112)	0.095 (0.113)
Interior space	0.025 (0.024)	0.000 (0.016)	0.006 (0.017)	0.016 (0.017)	-0.004 (0.013)
Wheelbase	0.188 (0.068 **)	0.054 (0.065)	0.036 (0.059)	0.001 (0.054)	-0.032 (0.057)
Weight	0.248 (0.059 **)	0.811 (0.103 **)	0.818 (0.084 **)	0.667 (0.086 **)	0.585 (0.084 **)
Seating capacity	-0.024 (0.015)	-0.039 (0.011 **)	-0.038 (0.011 **)	-0.053 (0.011 **)	-0.032 (0.011 **)
Fuel economy	-0.004 (0.003)	-0.007 (0.002 **)	-0.006 (0.002 **)	-0.013 (0.002 **)	-0.011 (0.003 **)
Engine displacement	0.125 (0.032 **)	0.006 (0.033)	-0.055 (0.025 *)	-0.026 (0.023)	0.025 (0.027)
Max power	0.288 (0.028 **)	0.192 (0.037 **)	0.206 (0.032 **)	0.192 (0.031 **)	0.151 (0.027 **)
Torque	0.000 (0.000)	0.003 (0.003)	0.004 (0.003)	0.002 (0.002)	-0.005 (0.002 *)
Air conditoner	0.017 (0.018)	-0.003 (0.019)	0.009 (0.018)	0.035 (0.018 *)	0.024 (0.018)
Auto air conditioner	0.099 (0.014 **)	0.082 (0.012 **)	0.089 (0.013 **)	0.094 (0.014 **)	0.091 (0.017 **)
Anti-lock brake	0.066 (0.018 **)	0.051 (0.014 **)	0.058 (0.012 **)	0.048 (0.015 **)	0.085 (0.014 **)
4WS	0.064 (0.018 **)	0.011 (0.019)	0.019 (0.020)	0.033 (0.012 **)	0.066 (0.018 **)
Air bags	0.107 (0.029 **)	0.059 (0.017 **)	0.050 (0.011 **)	0.072 (0.011 **)	0.048 (0.011 **)
Sunroof	0.068 (0.022 **)	0.018 (0.017)	0.027 (0.017)	0.008 (0.014)	0.018 (0.015)
Car navigation	-0.024 (0.079)	0.170 (0.050 **)	0.071 (0.050)	0.107 (0.023 **)	0.106 (0.024 **)
Hatchback	-0.010 (0.020)	-0.047 (0.017 **)	-0.059 (0.019 **)	-0.015 (0.018)	-0.042 (0.019 *)
Coupe	0.075 (0.023 **)	0.023 (0.020)	0.025 (0.019)	0.008 (0.017)	0.014 (0.017)
Hardtop	0.020 (0.014)	-0.020 (0.014)	0.010 (0.012)	0.016 (0.011)	0.016 (0.011)
Station wagon	0.022 (0.022)	-0.014 (0.020)	-0.008 (0.018)	0.029 (0.016 *)	0.006 (0.018)
Minivan	-0.024 (0.077)	-0.128 (0.061 *)	-0.115 (0.051 *)	-0.004 (0.048)	-0.026 (0.047)
Off-road vehicle	0.009 (0.072)	-0.204 (0.053 **)	-0.224 (0.043 **)	-0.164 (0.045 **)	-0.138 (0.043 **)
Standard car	-0.039 (0.027)	-0.012 (0.018)	0.005 (0.016)	0.032 (0.014 *)	-0.008 (0.015)
Mini car	-0.036 (0.045)	-0.030 (0.044)	-0.059 (0.048)	-0.042 (0.048)	-0.027 (0.050)
Diesel	0.084 (0.026 **)	0.041 (0.026)	0.011 (0.024)	0.088 (0.024 **)	0.046 (0.026 *)
V8 gasoline-fueled	-0.060 (0.048)	0.063 (0.048)	0.170 (0.038 **)	0.147 (0.033 **)	0.115 (0.039 **)
V6 gasoline-fueled	0.043 (0.019 *)	0.020 (0.017)	0.033 (0.014 *)	0.014 (0.015)	0.010 (0.014)
Rotary	0.094 (0.097)	0.134 (0.044 **)	0.254 (0.052 **)	0.164 (0.053 **)	0.234 (0.064 **)
4-speed automatic	0.066 (0.013 **)	0.051 (0.011 **)	0.067 (0.010 **)	0.045 (0.011 **)	0.060 (0.010 **)
4-speed floor	-0.166 (0.037 **)	-0.189 (0.026 **)	-0.178 (0.084 *)	-0.212 (0.033 **)	-0.246 (0.031 **)
FF	-0.012 (0.017)	-0.020 (0.015)	-0.020 (0.017)	-0.027 (0.015 *)	-0.044 (0.015 **)
4WD	0.057 (0.019 **)	-0.007 (0.018)	0.017 (0.018)	-0.004 (0.018)	-0.016 (0.017)
Nissan	0.016 (0.017)	0.025 (0.014 *)	0.031 (0.014 *)	0.024 (0.012 *)	-0.023 (0.013 *)
Mitsubishi	0.023 (0.020)	0.017 (0.016)	0.005 (0.016)	0.009 (0.015)	-0.008 (0.016)
Mazda	0.013 (0.017)	0.036 (0.017 *)	0.036 (0.018 *)	-0.026 (0.019)	-0.029 (0.018 *)
Honda	0.022 (0.018)	0.035 (0.015 **)	0.017 (0.017)	0.004 (0.014)	-0.017 (0.016)
Isuzu	0.054 (0.027 *)	0.004 (0.022)	-0.005 (0.025)	-0.004 (0.020)	-0.018 (0.020)
Fuji	-0.043 (0.023 *)	-0.044 (0.024 *)	-0.005 (0.018)	0.006 (0.016)	-0.020 (0.016)
Daihatsu	-0.008 (0.023)	0.037 (0.021 *)	0.053 (0.021 **)	0.022 (0.021)	-0.002 (0.020)
Suzuki	0.053 (0.034)	0.082 (0.034 **)	0.035 (0.037)	-0.007 (0.033)	0.028 (0.043)
Adjusted R^2	0.952	0.961	0.959	0.964	0.962
SSR	4.243	3.641	3.958	3.499	3.379
Nunber of sample	471	486	499	501	492

Note: White's (1980) heteroskedasticity-robust standard errors in parentheses, because the presence of heteroskedasticity is judged by Breusch-Pagan (1979) test; ** and * indicate statistical significance at the 1 and 5 % level, respectively.

consists of two steps: first, several common factors called the principal components are extracted from original explanatory variables; second, some of these principal components are used as new explanatory variables in the regression analysis.

Table A-2 summarizes the results of calculated principal components from the 1990-94 data on the eleven characteristics.[43] In terms of the eigenvalue, the first and second principal components dominate the other principal components. The eigenvalue divided by the number of characteristics indicates the proportion of total variations in all characteristics explained by the principal component. Therefore, the first and second principal components together explain the 82.9 % of the total variations in all the characteristics: the first principal component explains 58.2 % and the second 24.7 %.

The first principal component has positive large coefficients for all the characteristics except the fuel economy: this component apparently represents the extent of general automobile size. The second principal component has positive coefficients for wheelbase, maximum power, and torque, and negative coefficients for height, interior space, and seating capacity, reflecting the degree of sports car element versus passenger comfort. The third principal component has positive coefficients for height and torque, and negative coefficients for length, wheelbase, seating capacity, and fuel economy: unlike the first and second principal components, it is not apparent what it represents. Although the estimates are not shown for 1-year and 2-year data, the first and second principal components produce stable coefficients with the same signs in all sample periods. However, from the third component to eleventh component produce unstable coefficients whose signs often switch from year to year.

Table A-2
Principal Components for Full Sample Period Data

		Coefficient for principal componets										
Principal components	Eigen-value	Length	Width	Height	Interior space	Wheel-base	Weight	Seating capacity	Fuel economy	Engine displace-ment	Max power	Torque
1	6.399	0.910	0.887	0.239	0.463	0.705	0.933	0.415	-0.862	0.944	0.782	0.852
2	2.722	0.149	0.160	-0.903	-0.830	0.404	-0.206	-0.816	0.072	0.062	0.491	0.222
3	0.714	-0.311	-0.174	0.234	-0.154	-0.451	0.125	-0.267	-0.276	0.131	0.189	0.299
4	0.290	-0.011	-0.024	-0.172	0.146	-0.161	-0.151	0.206	0.187	-0.050	0.220	0.246
5	0.270	-0.101	-0.367	0.033	0.073	0.311	0.000	0.018	-0.062	-0.050	0.081	0.093
6	0.243	-0.061	0.024	0.127	-0.034	0.082	0.117	-0.085	0.356	0.150	-0.122	0.173
7	0.102	0.055	-0.059	-0.017	0.166	-0.047	0.057	-0.146	0.073	0.059	0.117	-0.135
8	0.093	0.115	0.010	0.017	0.077	-0.016	0.030	-0.119	-0.019	-0.193	-0.076	0.123
9	0.078	-0.070	0.108	0.133	-0.020	0.059	-0.023	-0.012	0.042	-0.120	0.145	-0.039
10	0.051	-0.055	0.060	0.014	0.092	0.037	-0.147	-0.068	-0.042	0.064	-0.041	0.031
11	0.039	0.122	-0.051	0.089	-0.054	-0.016	-0.093	0.002	0.015	0.032	0.022	0.001

[43]GAUSSX version 3.2 was used for calculation.

The above considerations lead to the conclusion that the characteristics of automobiles are mainly explained by the first principal component which represents size and the second one which represents the degree of sports car element. Thus, the hedonic function is estimated using these two principal components as explanatory variables.

Table A-3 presents the estimations for the hedonic functions with principal components as explanatory variables. It shows a high coefficient of determination (adjusted for degree of freedom). Moreover, these two principal components have high explanatory power with statistically significant at the 1 % level. Nevertheless, in comparison with the performance of the hedonic function, using three basic characteristics (maximum power, wheelbase, and interior space) as explanatory variables, the improvement in the coefficient of determination is only 0.01 (see Table 6-1 and Table 6-2 in the text). Therefore, there is no significant difference in performance between these two hedonic functions.

Furthermore, it is difficult to obtain an intuitive meaning of estimated parameters. Although it is clear that the first principal component represents size and the second the degree of sports car element, the coefficients for two principal components are changing

Table A-3
Estimation with Principal Components

		Adjusted R^2	SSR	Statistical significance	
				First principal component	Second principal component
Full sample estimation					
	90-94	0.946	27.423	⊙	⊙
2-year sample estimation					
	90-91	0.944	10.953	⊙	⊙
	91-92	0.947	10.702	⊙	⊙
	92-93	0.948	10.623	⊙	⊙
	93-94	0.951	9.556	⊙	⊙
1-year sample estimation					
	90	0.941	5.379	⊙	⊙
	91	0.949	4.897	⊙	⊙
	92	0.943	5.502	⊙	⊙
	93	0.951	4.864	⊙	⊙
	94	0.950	4.487	⊙	⊙

Note: ⊙ indicates statistical significant at 1% level.

every year, reflecting technical innovations, shift in consumer preferences, and change in sample data structure. This creates problems such as how to evaluate estimated parameters and how to check their stability. Moreover, it takes time to estimate various hedonic functions for different sample periods, and stylings and sizes, because different principal components need to be reestimated for different data sets.

Although principal component analysis has the advantage of reducing many characteristics into some mutually uncorrelated components and producing an overall good estimation performance, it faces the aforementioned problems. This paper, therefore, does not adopt the principal component approach to deal with multicollinearity.

C. Method for Diagnosing Multicollinearity

Arguea and Hsiao (1993) used statistical method developed by Belsley, Kuh and Welsch (1980) to deal with multicollinearity in estimation of a hedonic function for automobiles. Out of 15 characteristics, they selected the four variables (maximum power, wheelbase, luggage space, breaking system) that have high explanatory power and suffer less from multicollinearity.[44] In presenting the statistical method for diagnosing multicollinearity below, the argument of Minotani (1992) is followed.[45]

Suppose there are k characteristics represented by a vector $\mathbf{X}_j$ and their correlation matrix is given by $\mathbf{R}$. Let λ_j represent the eigenvalue of this matrix $\mathbf{R}$. Then the test statistics for multicollinearity are given by the following condition index:

$$K_j = \frac{\lambda_{max}}{\lambda_j} \quad . \qquad \text{(A-1)}$$

Belsley *et al.* (1980) proposed using this condition index according to the following:

(1) There is little multicollinearity if $K_j < 10$,
(2) There is some multicollinearity if $15 < K_j < 30$,
(3) There is serious multicollinearity if $K_j > 100$,
(4) There are multiple linear relationships if more than two K_j are greater than 100.

Next, the concepts of VIF (variance inflation factor) and VIF component are introduced to detect multicollinearity on regression coefficients. Diagonalize correlation matrix ($\mathbf{R}$) of characteristics and let $\mathbf{P}$ represent diagonal matrix with eigenvalues λ_i. Then increase in variance of estimated parameters is given by the following VIF_j :

[44] The 15 characteristics are the maximum power, length, width, weight, engine displacement, acceleration (from 45 km to 65 km), acceleration (from 0 to 60 km), braking system, minimum turning radius, seating capacity, luggage space, deceleration ratio, urban fuel economy, and suburb fuel economy.

[45] The argument of Minotani(1992) generally follows that of Belsley, Kuh, and Welsch (1980). The main difference is that Minotani bases the test of multicollinearity on the eigenvalue of the correlation matrix of explanatory variables. In other words, Minotani argues for using the eigenvalue of the correlation matrix that is not affected by the scale of explanatory variables, while Belsley et al. argue for using the eigenvalue of the moment matrix.

$$VIF_j = \sum_{i=1}^{k} \frac{P_{ji}^2}{\lambda_i} \qquad (i = 1, 2, \ldots, k) \quad . \tag{A-2}$$

The contribution of λ_i in VI_j is given by the following proportion π_{ji} :

$$\pi_{ji} = \frac{P_{ji}^2/\lambda_i}{VIF_j} \qquad (i, j = 1, 2, \ldots, k) \quad , \tag{A-3}$$

where

$$\sum_{i=1}^{k} \pi_{ji} = 1 \tag{A-4}$$

holds.

Equation (A-2) indicates that the smaller the eigenvalue and the greater the absolute value of the element (p_{ji}) of the eigenvector, the greater is the VIF_j, and variance of estimated parameters. Although a small eigenvalue implies high multicollinearity, it is important to note that it does not affect all estimated parameters. Even if strong multicollinearity exists, variance of estimated parameters could be small so long as the explanatory variables $\mathbf{X}_j$ is not involved in the multicollinearity when all p_{ji}, π_{ji}, and VIF_j have small values. If so, the estimated parameters could be stable.

Next, I calculate the condition index, VIF, and VIF component and detect multicollinearity.[46] Table A-4 presents the results based on the 1994 data. There are three condition indexes that exceed 100, implying the presence of serious multicollinearity. There are also three other condition indexes that exceed 30, which implies some

Table A-4
Condition Indexes and VIF Components (1994)

Eigen-value	Condition index	Length	Width	Height	Interior pace	Wheel-base	Weight	Seating capacity	Fuel economy	Engine displace-ment	Max power	Torque
6.561	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01
2.540	2.58	0.00	0.00	0.00	0.01	0.04	0.00	0.00	0.00	0.00	0.00	0.01
0.867	7.57	0.00	0.02	0.01	0.01	0.02	0.00	0.00	0.03	0.02	0.01	0.00
0.284	23.11	0.01	0.06	0.02	0.05	0.00	0.00	0.00	0.02	0.07	0.02	0.06
0.263	24.94	0.03	0.01	0.10	0.01	0.55	0.00	0.00	0.01	0.01	0.00	0.02
0.197	33.37	0.06	0.01	0.02	0.03	0.02	0.01	0.18	0.09	0.01	0.00	0.08
0.095	69.10	0.08	0.08	0.03	0.34	0.00	0.00	0.15	0.12	0.10	0.02	0.05
0.085	77.15	0.15	0.00	0.03	0.03	0.00	0.05	0.00	0.31	0.20	0.13	0.18
0.048	138.13	0.24	0.03	0.18	0.14	0.04	0.14	0.59	0.33	0.01	0.00	0.29
0.040	163.41	0.27	0.00	0.19	0.00	0.04	0.81	0.05	0.08	0.01	0.03	0.01
0.021	316.74	0.15	0.79	0.42	0.38	0.28	0.00	0.02	0.00	0.57	0.79	0.29

[46]The estimation was effected by GAUSS version 3.0.

multicollinearity. The VIF component corresponding to the largest condition index (316.74) exceeds 0.25 for the seven variables: the width, height, interior space, wheel-base, engine displacement, maximum power, and torque. It suggests that the variance of the estimated parameter is magnified. The VIF component corresponding to the second largest condition index (163.41) exceeds 0.25 for the two variables: the length and weight.

Repeating this step for each sample period, the presence of multicollinearity is ascertained. Table A-5 presents the condition index for each sample period. There are one to three condition indexes that exceed 100 in each sample period, which imply serious multicollinearity, and five to six condition indexes that exceed 30. This implies that some five to six pairs of multicollinearity exist in each year, and therefore that effective explanatory variables are at most five. The calculated VIF component in each year implies that every characteristic is involved in some multicollinearity, and no characteristics are completely free from the problem of multicollinearity. Hence, I cannot select good explanatory variables from this diagnostic test.

Consequently, several hedonic functions are estimated for various combinations of explanatory variables. The selection of good explanatory variables is determined by comparing the goodness of fit, sign conditions, and stability of the estimated parameters.

Table A-5
Condition Indexes

Full	2-year				1-year				
	90-91	91-92	92-93	93-94	90	91	92	93	94
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2.4	2.1	2.3	2.5	2.6	2.0	2.2	2.4	2.6	2.6
9.0	8.9	9.9	9.6	8.3	8.1	9.7	10.0	9.1	7.6
22.1	17.1	22.6	23.3	23.6	13.3	21.4	22.6	23.9	23.1
23.7	22.1	25.2	25.1	24.9	20.4	25.6	25.6	24.8	24.9
26.3	26.5	25.8	30.0	33.3	27.0	26.2	27.2	33.9	33.4
63.0	42.0	69.4	68.4	68.1	35.9	66.1	72.9	65.5	69.1
68.5	61.1	86.5	89.9	81.5	50.6	84.3	90.0	90.8	77.1
82.4	79.5	127.5	139.9	147.9	74.5	123.2	126.5	157.9	138.1
124.5	90.1	176.0	193.5	183.3	88.9	178.3	185.4	209.3	163.4
164.4	150.4	293.4	313.4	321.8	144.5	310.0	304.8	341.0	316.7

D. Selection of Explanatory Variables

Out of 11 characteristics, various combinations are tried to select three basic performance characteristics representing engine power, automobile size, and interior size. Estimation was conducted for 1-year, 2-year, and full sample period data sets to find out the best fit combination of performance characteristics. Candidates for the three basic characteristics are maximum power, torque, and engine displacement for engine power; length, wheelbase, and weight for automobile size; and interior space, seating capacity, and height for interior size. That is, there are total of nine candidates: three candidates for each of the tree basic categories of characteristics.

The combination of the three basic performance characteristics is appropriate for two reasons. First, as shown by the principal component analysis mentioned above, the two concepts, automobile size and sports car element, are important performance characteristics. These concepts should be covered by the three basic characteristics engine power, automobile size, and interior size. Second, estimated hedonic functions with more than four characteristics exhibit the increased instability of estimated parameters, and the existence of multicollinearity also become visible. This suggests that to obtain reliable estimation results, the number of explanatory variables needs to be limited to three variables at most.

Table A-6 presents the coefficients of determination (adjusted for the degree of freedom) for hedonic functions with various combination of explanatory variables. They are about 0.92-0.96 for all combinations and the fitness of estimated equations is deemed good for all combinations. Therefore, the selection is going to be determined by looking at the signs and stability of the estimated parameters.

The results of estimation suggest that maximum power performs very well as an indicator for engine power. As for automobile size, weight appears to perform well in terms of the coefficient of determination; but, it results in a wrong sign for interior size in many cases. Therefore, either length or wheelbase should be used for automobile size. Although they both produce similar results, the wheelbase seems to be slightly superior to length in terms of statistical significance and sign conditions of the estimated parameters. Finally, as for interior size, the interior space seems to be superior in terms of technical characteristics, although the results are similar.[47]

In conclusion, the present analysis adopts the maximum power, wheelbase, and interior space as the three basic characteristics for automobiles as the explanatory variables in the hedonic functions.

Finally, Let me check whether technical characteristics of automobiles are well captured by the three characteristics. This is done by regressing each excluded characteristic on these three basic characteristics as explanatory variables. The coefficients of

[47]The degree of freedom will be lost if seating capacity is used as a measure of interior size, because that of mini cars is all four persons. Therefore, seating capacity is inappropriate.

Table A-6
Combination of Variables and Estimation Fits

Variables			Full	2-Year				1-Year					
Engine	Size	Interior	90-94	90-91	91-92	92-93	93-94	90	91	92	93	94	Ave.
Max power	Weight	Seats	0.956	0.951	0.959	0.960	0.961	0.944	0.961	0.957	0.962	0.959	0.957
Max power	Weight	Space	0.955	0.951	0.959	0.959	0.960	0.946	0.960	0.956	0.960	0.959	0.956
Max power	Weight	Height	0.955	0.952	0.959	0.958	0.959	0.945	0.960	0.956	0.960	0.958	0.956
Torque	Weight	Seats	0.945	0.936	0.954	0.954	0.956	0.924	0.957	0.951	0.956	0.954	0.949
Torque	Weight	Space	0.944	0.936	0.954	0.953	0.954	0.925	0.956	0.950	0.953	0.953	0.948
Torque	Weight	Height	0.943	0.936	0.953	0.952	0.953	0.924	0.956	0.950	0.953	0.952	0.947
Max power	Length	Height	0.946	0.947	0.944	0.947	0.949	0.946	0.945	0.942	0.951	0.946	0.946
Max power	Length	Space	0.945	0.945	0.942	0.945	0.948	0.945	0.943	0.940	0.950	0.945	0.945
Max power	Length	Seats	0.945	0.945	0.942	0.945	0.948	0.944	0.943	0.940	0.950	0.944	0.945
Disp	Weight	Seats	0.940	0.937	0.945	0.944	0.947	0.930	0.949	0.941	0.947	0.944	0.942
Disp	Weight	Space	0.939	0.936	0.945	0.943	0.944	0.930	0.948	0.941	0.944	0.941	0.941
Max power	Wheelbase	Height	0.940	0.942	0.941	0.941	0.942	0.940	0.942	0.939	0.943	0.940	0.941
Max power	Wheelbase	Space	0.940	0.942	0.940	0.941	0.942	0.941	0.941	0.938	0.944	0.939	0.941
Disp	Weight	Height	0.938	0.936	0.943	0.942	0.943	0.930	0.947	0.939	0.944	0.940	0.940
Max power	Wheelbase	Seats	0.938	0.940	0.938	0.939	0.941	0.938	0.939	0.935	0.942	0.938	0.939
Torque	Length	Height	0.929	0.922	0.944	0.945	0.948	0.918	0.945	0.942	0.947	0.947	0.939
Torque	Length	Seats	0.929	0.921	0.943	0.946	0.949	0.918	0.944	0.941	0.949	0.947	0.939
Torque	Length	Space	0.928	0.921	0.943	0.945	0.947	0.918	0.944	0.941	0.947	0.947	0.938
Torque	Wheelbase	Space	0.920	0.912	0.941	0.941	0.942	0.905	0.943	0.938	0.941	0.942	0.933
Torque	Wheelbase	Height	0.920	0.912	0.941	0.941	0.942	0.904	0.943	0.939	0.940	0.942	0.932
Torque	Wheelbase	Seats	0.920	0.911	0.940	0.941	0.943	0.904	0.942	0.938	0.942	0.942	0.932
Disp	Length	Seats	0.926	0.923	0.922	0.927	0.935	0.919	0.924	0.919	0.934	0.932	0.926
Disp	Length	Height	0.925	0.923	0.922	0.926	0.932	0.920	0.924	0.919	0.931	0.930	0.925
Disp	Length	Space	0.925	0.923	0.922	0.926	0.932	0.919	0.924	0.918	0.931	0.930	0.925
Disp	Wheelbase	Seats	0.921	0.919	0.919	0.923	0.929	0.916	0.922	0.916	0.928	0.927	0.922
Disp	Wheelbase	Height	0.920	0.919	0.919	0.921	0.927	0.916	0.921	0.916	0.925	0.925	0.921
Disp	Wheelbase	Space	0.920	0.919	0.919	0.921	0.926	0.916	0.921	0.916	0.925	0.924	0.921

Note: 1. Descending orders by the coefficient of determinant.
2. Disp = engine displacement; Seats = seating capacity; Space = interior space.

Table A-7
Auxiliary Regressions

	1990	1991	1992	1993	1994
Length	0.793	0.825	0.821	0.820	0.817
Width	0.616	0.644	0.669	0.660	0.644
Height	0.818	0.757	0.718	0.672	0.631
Weight	0.731	0.779	0.741	0.720	0.684
Seating capacity	0.821	0.821	0.837	0.832	0.840
Fuel economy	0.657	0.621	0.621	0.666	0.643
Engine displacement	0.729	0.771	0.762	0.745	0.717
Torque	0.843	0.902	0.866	0.850	0.843

determination (adjusted for degree of freedom) of such regressions are listed in Table A-7. They range from 0.6 to 0.9, indicating that excluded characteristics are well represented by the selected three basic ones.

Appendix 2. Grouping of Automobiles by Multivariate Analysis

Regarding the analytical framework in this paper, Appendix 1 shows that principal component analysis is not a good method to handle the problem of multicollinearity. Nevertheless, the estimated principal components are found to represent automobile size (first principal component) and sports car element (second one). In addition, these two principal components well captures most of the characteristics of automobiles. Therefore, using the principal component analysis, this appendix attempts to characterize automobiles of different sizes and stylings.

Table A-8 presents the average and standard deviation of the first and second principal components for each size and styling. The average value of the first principal component is largest for standard cars and negative for small and mini cars, which is, off course, quite a natural outcome. Moreover, the same holds for the second principal component, indicating that the "sports car element" is greater for larger automobiles.

Table A-8
Averages and Standard Deviations for Principal Components by Size and Styling

	Average		Standard deviation	
	First principal component	Second principal component	First principal component	Second principal component
Size				
Standard car	0.950	0.062	0.504	1.208
Small car	-0.176	-0.027	0.549	0.958
Mini car	-1.909	-0.051	0.113	0.226
Styling				
Sedan	0.187	0.360	0.661	0.260
Hatchback	-1.296	0.067	0.716	0.211
Coupe	0.372	1.043	0.643	0.465
Hardtop	0.643	0.563	0.581	0.209
Station wagon	0.121	-0.283	0.729	0.508
Minivan	0.532	-2.689	0.768	0.541
Off-road vehicle	0.731	-0.628	0.789	0.566

The standard deviations of the first and second principal components are similar for standard and small cars, but relatively small for mini cars. This implies that standard and small cars have more variety in size and sports car element, while mini cars have similar characteristics.

Next, let me look at the figures for different stylings of automobiles. Average value of the first component has a large value for hardtops, minivans, and off-road vehicles, while it has a negative value for hatchbacks. This perhaps reflects the fact that hardtops mostly belong to standard cars, while most mini cars belong to hatchbacks. The second component has a large value for sporty cars like the coupes and hardtops while it has a small value for RV-type vehicles like station wagons, minivans, and off-road vehicles.

In this way, it is possible to identify the characteristics of different groups of automobiles just by comparing the averages and standard deviations of the principal components.[48] This example has shown that the multivariate analysis, such as the principal component analysis, is a very effective way to identify the characteristics of data consisting of many different kinds of samples, and to divide them into some basic groups.

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[48]The t-test can check if the averages of different samples are identical, and the F-test can check if the standard deviations of different samples are identical. See Manly (1992) for details.

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