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Automobile Prices Revisited: Extensions of

the Hedonic Hypothesis *

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I. INTRODUCTION

THE "hedonic" approach to price indexes has been reviewed recently in a number of places (Gordon 1973, Griliches 1971, Muellbauer 1972, Ohta 1973, and Rosen 1973, among others) and we will not go over the same ground again except for a few brief remarks. The hedonic hypothesis assumes that a commodity can be viewed as a bundle of characteristics or attributes for which implicit prices can be derived from prices of different versions of the same commodity containing differing levels of specific characteristics. The ability so to disaggregate a commodity and price its components facilitates the construction of price indexes and the measurement of price change across differing versions of the same commodity. Several issues arise in trying to implement such a program: (1) What are the relevant characteristics of a commodity bundle? (2) How are the implicit prices to be estimated from the available data? (3) How are the resulting estimates to be used to construct price or quality indexes for a particular commodity? (4) What meaning, if any, is to be given to the

resulting constructs? What do such indexes measure and under what conditions do they measure it unambiguously?

Much of the recent critical literature on the hedonic approach has dealt with the last two questions, pointing out the restrictive nature of the assumptions required to establish the "existence" and meaning of such indexes. While instructive, we feel that this literature has misunderstood the original purpose of the hedonic suggestion. It is easy to show that except for unique circumstances and under very stringent assumptions, it is not possible to devise a perfect price index for *any* commodity classification. With finite amounts of data, different procedures will yield (hopefully not very) different answers, and even "good" formulae, such as Divisia-type indexes, cannot be given a satisfactory theoretical interpretation except in very limiting and unrealistic circumstances. Most of the objections to attempts to construct a price index of automobiles from the consideration of their various attributes apply with the same force to the construction of a motor-vehicles price index out of the prices of cars, trucks, and motorcycles.

Despite the theoretical proofs to the contrary, the Consumer Price Index (CPI) "exists" and is even of some use. It is thus of some value to attempt to improve it even if perfection is unattainable. What the hedonic approach attempted was to provide a tool for estimating "missing" prices, prices of particular bundles not observed in the original or later periods. It did not pretend to dispose of the question of whether various observed differentials are demand or supply determined, how the observed variety of models in the market is generated, and whether the resulting indexes have an unambiguous welfare interpretation. Its goals were modest. It offered the tool of econometrics, with all of its attendant problems, as a help to the solution of the first two issues, the detection of the relevant characteristics of a commodity and the estimation of their marginal market valuation.

Because of its focus on price explanation and its purpose of "predicting" the price of unobserved variants of a commodity in particular periods, the hedonic hypothesis can be viewed as asserting the existence of a reduced-form relationship between prices and the various characteristics of the commodity. That relationship need not be "stable" over time, but changes that occur should have some rhyme and reason to them, otherwise one would suspect that the observed results are a fluke and cannot be used in the extrapolation necessary for the derivation of missing prices. All this has an air of "measurement without theory" about it, but one should remember the

limited aspirations of the hedonic approach and not confuse it with attempts to provide a complete structural explanation of the events in a particular market.

To accomplish even such limited goals, one requires much prior information on the commodity in question (econometrics is not a very good tool when wielded blindly), lots of good data, and a detailed analysis of the robustness of one's conclusions relative to the many possible alternative specifications of the model. In what follows, we take up a few limited topics in the analysis of automobile prices, focusing on the role of "makes" or "brands" in explaining price differentials among different models of automobiles, the additional information to be derived from analyses of used car prices, and the gains to be had, if any, from using performance instead of physical (specification) characteristics in defining the relevant attributes of a commodity.

II. QUESTIONS, MODELS, AND RESEARCH STRATEGY

A. Preliminaries

We distinguish between the physical characteristics of a car (x_1, $x_2, \ldots , x_m$) and its performance variables ($y_1, y_2, \ldots , y_n$). Physical characteristics (specifications) are such things as horsepower, weight and length, while acceleration, handling, steering, accommodation, and fuel economy are performance variables. In our general setting, physical characteristics of a car enter the cost function of producing it but do not affect the utility function of the consumer directly.[1] We postulate a "two-stage hypothesis" which asserts that the physical characteristics of a car produce its performance.[2]

Note that the mapping from physical characteristics to performance variables need not be one to one. Some performance levels, such as engine performance and accommodation indexes, are produced by the physical characteristics and are costly. These are closely connected with the physical characteristics of power and size. But other performance variables, such as prestige or design differences, cost little and may not be related to measured physical characteristics. They may be produced by demonstration effects, advertising, and good service and quality-control policies. The mapping may also be stochastic

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[1] Tautologically, we consider those attributes of a car that enter the cost function as its physical characteristics and those that enter the consumers' utility function as performance variables. There may be some attributes which enter both functions. These are performance variables as well as physical characteristics.

[2] Our "two-stage hypothesis" is similar to the idea of "consumption activity" in Lancaster (1966).

rather than deterministic and it may change over time. Experienced and inexperienced drivers may get different performances from a car with the same physical characteristics. Users may get accustomed to a car over time by learning to deal with its idiosyncrasies. And, most important for our purposes, unmeasured physical characteristics may change the relationship between measured physical characteristics and performance levels over time.

We consider performance variables as well as physical characteristics because, ideally, quality adjustments should be based on performance variables, which presumably enter the utility function directly, rather than on physical characteristics. If the transformation function from physical characteristics to performance levels shifts systematically over time, then hedonic price indexes based on physical characteristics alone will be biased.[3]

So far, we have discussed our model only in general terms. One cannot, however, solve all problems immediately and simultaneously. The most general model is rarely operational. We have chosen, therefore, to concentrate on finding an appropriate strategy for each specific problem. Because the number of observations available on performance variables is very limited, we postpone the discussion of tests of the two-stage hypothesis to the last section of this paper, concentrating first on narrowing down the range of possible alternative models, using the much larger physical characteristics sample.

The typical regression model which we shall use throughout the empirical sections of the study is based on the following semilogarithmic form

$$P_{kits} = Const. \cdot M_i \cdot \bar{P}_t \cdot D_s \cdot e^{\sum_j a_{tj} x_{kivj}}$$

where

P_{kits}: price of model k of make i and age s at time t
   M_i: effect of the ith make (the effect of make 1 is set at 1)
   $\bar{P}_t$: pure (hedonic) price index at time t
   D_s: effect of age s (depreciation)
   a_{tj}: parameter reflecting the imputed price of physical characteristic j at time t
x_{kivj}: the level of the physical characteristic j embodied in model k of make i and vintage v ($v = t - s$)

We chose the semilogarithmic form as our basic regression equation

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[3] See, for example, Triplett (1966).

for the same reasons as those reported by Griliches (1961); it provided a good fit to the data. In the following chapters we shall also, occasionally, allow D_s to depend on make (i) and time (t), and a_i to depend on age (s), make (i), time (t), and on whether the car is new or used. That is, generally, we can write

$$D_s = D_s(i, t)$$

$$a_{ti} = a_j(s, j, t, \text{new or used})$$

In some of the empirical sections, we shall restrict D_s to an exponential function of s, and when we study performance variables y, we shall substitute them for the physical characteristics x in this type of model.

B. Make-Effects [4]

Because hedonic studies try to infer the marginal market valuation of different characteristics from observed market data, they require observations on models or variants of the commodity that differ significantly in the combination and range of characteristics contained in them. To accomplish that, and to increase sample size, authors are tempted to define the commodity broadly and to assume that there is enough substitution and competition across various boundaries to lead to relatively stable equalizing price differentials. One of the major boundaries that such studies cross are those connected with makes or brands. The essence of the hedonic approach is the assumption that one can find a metric for crossing such boundaries, that specifying the underlying characteristics creates adequate conmensurability. However, since the list of measurable characteristics is never complete, there may be systematic differences across makes in the levels of the "left-out" variables, real (physical) or putative. This will not create too serious a problem provided that these left-out variables are "separable" from the measured characteristics and constant over time. Given several observations per make or brand and repeated

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[4] Griliches (1967) first pointed to model effects as a possible source of the observed fluctuations in the estimated hedonic price indexes and warned that without further analysis of the size of the model effect, we should not interpret the time dummy estimates of hedonic regression equations as unbiased estimates of pure price change, unless the size and composition of samples are kept constant over time. He thought of it primarily as the effect of left-out physical characteristics making it a special case of the omitted variables problem. He did not consider the role of market structure and related brand loyalty considerations as potentially important sources of such effects. We shall pursue this lead but use the "make" rather than the model as our unit of classification and object of study. We do this because various market structure hypotheses appear to be more relevant at the make or even manufacturer level and because the classification at the model level is much too fine for empirical study.

observations over time, some of these hypotheses are testable. Since "make effects" are also of intrinsic interest, we devote a major part of our effort in this study to their identification and analysis.

Imagine a new car market dominated by markup pricing. Let r_i be the markup ratio for make i, W the input price index, z_{ki} the output of model k of make i, and $c = C(.)$ the unit cost function connecting these variables.[5] Suppose that physical characteristics $x_{ki1}, \ldots, x_{kih}$ are measurable, while $x_{kih+1}, \ldots, x_m$ are not measurable. To simplify exposition, suppose that

$$c = C(x) = C_1(x_{ki1}, \ldots, x_{kih}) \cdot C_2(x_{kih+1}, \ldots, x_m)$$

i.e., it is separable in the unobserved characteristics. Then, we can write equation 1 as follows

$$P_{ki} = \underbrace{(1 + r_i)} \cdot \underbrace{C(x_{ki1}, \ldots, x_{kih}}, \underbrace{x_{kih+1}, \ldots, x_{kim}}; \underbrace{\Sigma Z_{ki}, W)}$$

reflects dif-	measured	unmeasured	not in-
ferential	characteristics	characteristics	cluded
market		$\downarrow$	in the
power		omitted	hedonic
across		variables	regression
makes			equation[6]

$$= \underbrace{(1 + r_i) \cdot C_2(x_{kih+1}, \ldots, x_{kim}: \Sigma z_{ki}, W)} \cdot \underbrace{C_1(x_{ki1}, \ldots, x_{kih}: \Sigma z_{ki}, W)}$$
$$\text{make-effect } M_i \qquad\qquad\qquad \text{hedonic part}$$

There are thus two paths through which the make effect M_i comes into a hedonic equation: the markup ratio r_i and the cost function C_2, whose arguments are the left-out physical characteristics. Accordingly, we can differentiate between two kinds of make-effects: "real" and "putative."

A "real" make-effect is the consequence of unmeasured, left-out

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[5] In the used car market, sellers as well as buyers are users of the automobile, not its producers. Hence, the cost function does not appear explicitly in this market. But the interpretation of the model effect in the new car market applies also to the used car market.

[6] Total output level $\sum_k z_{ki}$ and the input price index W are usually not included in hedonic regression equations. This is partly because the orthodox hedonic hypothesis tried to explain price solely by the physical characteristics of goods and partly because it did not pay much attention to the economic rationale underlying the hedonic regression equation. Ohta (1971) is an exception.

physical characteristics which enter the cost function, such as durability and body strength, and costly performance variables which are highly related to left-out physical characteristics, such as reliability (repair record), fuel economy, and so forth.[7] Since real model effects are based on physical characteristics, they will persist in the used car market and hence can be thought of as "permanent."

A "putative" make-effect is not based on physical characteristics and hence does not enter the per unit cost function of producing the good, though it may enter the utility function and the cost function (profit function) of sales. This effect does not come through the cost function C_2, whose arguments are left-out physical characteristics, but is reflected in the markup ratio r_i. Examples of this are prestige, reputation, and services availability. They are not "costless," but their cost does not depend closely on the current volume of output. Such effects may also persist in the used car market, though their durability may be lower than that of effects based on unmeasured physical characteristics.

The firm's pricing policy is based on the make-effect. If it is positive and large, then the price listed by the firm will be high relative to the level of the included physical characteristics. If the make-effect is negative, the price will be low relative to the level of the included physical characteristics. The firm will, however, sometimes overprice or underprice relative to its permanent make-effect. The overpricing or underpricing (i.e., the pricing error) will decrease or increase its market share in the new car market,[8] and will disappear (i.e., will not persist) in the used car market. This will also affect the observed depreciation rates in the used car market. A large transitory effect will result in a larger rate of depreciation. Hence the study of depreciation patterns is interrelated with the study of make-effects.

C. Major Questions

It is clear from our earlier discussion that our main interests center on (1) the study of make-effects, including a reexamination of

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[7] As will be shown later, fuel economy is relatively well explained by the standard set of physical characteristics (horsepower, weight, length, V-8 or not, hardtop or not). But Gordon (1971) showed that the gas mileage of closely similar low-priced models increased from 14.2 in 1959 to 15.9 in 1970. This improvement in the gas mileage implies that fuel economy depends not only on the standard set of physical characteristics but also on unknown, left-out design characteristics.

[8] See Cowling and Raynor (1970), Cowling and Cubbin (1970) and Triplett and Cowling (1971) for work along these lines. The idea was suggested by Griliches (1961), p. 177.

Dhrymes's (1967) test of equality of imputed prices of physical characteristics across manufacturers and makes, (2) depreciation patterns, and (3) the role of performance variables. More specifically, we are interested in the following questions:

(1) Can we observe make-effects in the new car market and in the used car market? Do the effects observed in the new car market persist in the used car market?

(2) Do make-effects affect the depreciation pattern so that different makes depreciate differently? Or, do they depreciate at the same rate as physical characteristics?

(3) Do performance variables explain enough of the variation in prices to allow us to substitute them successfully for physical characteristics in a hedonic regression?

(4) Does the recognition of make-effects affect hedonic price index computations seriously? Are indexes based on performance variables very different from those based on physical characteristics?

(5) Are the imputed prices of physical characteristics constant across different makes and manufacturers? If this were not true, at least approximately, it would seriously undermine the hedonic hypothesis. Are the imputed prices of the characteristics the same in the used and new car markets? Differences could be caused by the differing tastes of consumers in the new and used car markets, by pricing errors in the new market, and/or by differential depreciation patterns of the various characteristics. Do the imputed prices of the characteristics shift over time? If they do, it would indicate either changing supply conditions or shifts in consumer tastes.

(6) Are depreciation rates of different physical characteristics the same? This is equivalent to the question of whether imputed prices of physical characteristics are the same across age at a given point in time and is similar to the question of whether technical progress is neutral.[9] Is depreciation exponential? Are the rates stable over time?

D. The Relationship among the Various Hypotheses

We have already mentioned some of the hypotheses that have to be assumed explicitly or implicitly to allow one to use the standard single-equation hedonic approach. This section tries to lay out and to organize the relationship among the various hypotheses, starting from the most general hedonic equation and then narrowing it down by imposing additional restrictions in as nested a form as possible. A

[9] This question was first raised by Griliches (1971) in commenting on Hall (1971).

pictorial representation in the form of a nested tree of hypotheses is given in Figure 1. Starting at the top, we have:

(1) The most general form of the hedonic hypothesis is the "two-stage hypothesis in general functional form and without any un-measured performance variables and physical characteristics." Let P_{ts} be a price of a good of age s at time t. Let $s = 0$ mean that the good is new. Let $y = (y_1, y_2, \ldots, y_n)$ be its performance variables, and $x = (x_1, x_2, \ldots, x_m)$ be its physical characteristics when new. Then, the two-stage hypothesis can be written as follows, in general.

$$P_{ts} = h(y_1, \ldots, y_l, y_{l+1}, \ldots, y_n, s, t)$$

$$\left.\begin{cases} y_1 = f_1(x_1, \ldots, x_m, t) \\ \ \vert \\ \ \vert \\ \ \vert \\ y_l = f_l(x_1, \ldots, x_m, t) \end{cases}\right\} \text{costly performance variables}$$

$y_{l+1}, \ldots, y_n$ no-cost performance variables

(2) The two-stage hypothesis can be reduced to a "one-stage hypothesis, using only physical characteristics without any unmeas-ured characteristics in a general functional form," if there are no no-cost performance variables. The one-stage hypothesis can be written as follows:

$$P_{ts} = g(x_1, \ldots, x_m, s, t)$$

The one-stage hedonic approach based on physical characteristics may result, however, in a biased hedonic price index if the transforma-tion function f from x to y depends on time t.

(3) In order to reduce the general hedonic functional form g to the familiar semilogarithmic form and interpret it as something more than just a convenient approximation, one has to assume some hypotheses about utility and cost functions, such as the input-output separability of the production technology and the nonjointness of the physical char-acteristics as outputs in the cost function and in the utility function. In general, the functional form g of the hedonic hypothesis is deter-mined simultaneously by the functional forms of the demand and the supply curves of the various characteristics.[10] The semilogarithmic

[10] Ohta (1971) studies the problem of specification of the functional forms for the hedonic hypothesis in some detail.

FIGURE 1

Nested Tree of the Hypotheses in the Hedonic Study

(1)
> Two-stage hedonic hypothesis without any unmeasured performance variables y and physical characteristics x in a general functional form

(2)
> H_0: No no-cost performance variables
> (H_0: No change in the transformation from x to y over time)

(2)
> One-stage hedonic hypothesis using only the physical characteristics (without any unmeasured characteristics) in general functional form

(3)
> Hypotheses about the functional form of the hedonic equation (i.e., hypotheses about the utility function of consumers and the production technology of firms)

(3)
> Semilogarithmic hedonic form:
> $$\log (P_{kitv}) = \pi_{tv} + \sum_{j=1}^{m} a_{tsj}\, x_{kivj}$$

(4)
> Measured physical characteristics: $x_{kiv1}, \cdots, x_{kivh}$
> Unmeasured physical characteristics: $x_{kivh+1}, \cdots, x_{kivm}$

(4)
> General hedonic hypothesis:
> $$\log (P_{kitv}) = \pi_{itv} + \sum_{j=1}^{h} a_{itsj}\, x_{kivj} \quad (s = t - v)$$

(5)
> H_0: $a_{itsj} = a_{itj}$ (Particularly, it includes the hypothesis of equal relative imputed prices of physical characteristics in the new and the used car markets.)

(6)
> H_0: $a_{itj} = M_1^* a_{tj}$

(7)
> H_0: $M_i^* = 1$

(7)
> $$\log (P_{kitv}) = \pi_{its} + \sum_{j=1}^{h} a_{tj}\, x_{kivj}$$

(8)
> H_0: $\pi_{itv} = \bar{M}_v + \pi_{its} \quad (s = t - v)$

(9)
> H_0: $\bar{M}_v = C$

(9)
$$\log(P_{kitv}) = \pi_{its} + \sum_{j=1}^{h} a_{tj} \ x_{kivj}$$

(10)
$H_0 : \pi_{its} = \bar{P}_t + \pi_{is}$

Especially, this means:

(a) $H_0 : M_{its} = M_{is}$ (M_{its}: Make-effect of make i of age s at time t)

(b) $H_0 : D_{its} = D_{is}$ (D_{its}: Depreciation effect of age s of make i at time t)

(11)
$H_0 : \pi_{is} = M_i + D_s$

Especially, this means:

(a) $H_0 : D_{is} = D_s$ (D_{is}: Depreciation effect of age s of make i)

(b) $H_0 : M_{is} = M_i$ (M_{is}: Make-effect of make i at age s)

Particularly, (b) implies the same make-effects in the new and used car markets.

(11)
$$\log(P_{kitv}) = \bar{P}_t + M_i + D_s + \sum_j a_{tj} \ x_{kivj}$$

Equation 1 of Section 1

(17) $H_0 : a_{tj} = a_j$

(18) $H_0 : M_i = 0$

(12)
$H_0 : D_s = D_1 - \delta(s-1)$

(13)
$H_0 : D_s = -\delta s$

$H_0 : \pi_{is} = M_i - \bar{\delta}_i s$

$H_0 : \bar{\delta}_i = \bar{\delta}$

(14)
$H_0 : \pi_{is} = M_{it} \ D_{i1} - \delta_i(s-1)$

(15)
$H_0 : \delta_i = \delta$

(16)
$H_0 : D_{i1} = D_1$

NOTE: The attached numbers refer to hypotheses listed in the text. Symbols also are defined in the text.

form can be written as follows, taking the automobile as an example

$$\log (P_{kitv}) = \pi_{tv} + \sum_{j=1}^{m} a_{tsj}x_{kivj} \qquad (s = t - v)$$

where P_{kitv} is the price of a car of model k of make i and vintage v at time t, and x_{kivj} is the jth physical characteristic of model k of make i and vintage v.

(4) When there are unmeasured physical characteristics (x_{kivh+1}, ..., x_{kivm}), the above semilogarithmic form can be rewritten as follows, using the earlier discussion of make-effects

$$\log (P_{kitv}) = \pi_{itv} + \sum_{j=1}^{h} a_{itsj}x_{kivj} \qquad (s = t - v)$$

where π_{itv} now also incorporates make effects.

(5) If the hypothesis of equal depreciation across the physical characteristics or, equivalently, the hypothesis of equal relative imputed prices of the physical characteristics (H_0: $a_{itsj} = a_{itj}$ for any s) holds, the semilogarithmic form simplifies to

$$\log (P_{kitv}) = \pi_{itv} + \sum_{j=1}^{h} a_{itj}x_{kivj}$$

This hypothesis includes as a particular case the hypothesis of equal relative imputed prices of physical characteristics in both the new and the used car markets.

(6) If the hypothesis of equal relative imputed prices of the physical characteristics across makes (H_0: $a_{itj} = M_i^* a_{tj}$) is satisfied, the equation simplifies further to

$$\log (P_{kitv}) = \pi_{itv} + M_i^* \sum_{j=1}^{h} a_{tj}x_{kivj}$$

(7) If the hypothesis of no multiplicative make-effects (H_0: $M_i^* = 1$) is satisfied, the equation reduces to:

$$\log (P_{kitv}) = \pi_{itv} + \sum_{j=1}^{h} a_{tj}x_{kivj}$$

(8) If the hypothesis of the separation of vintage-specific effects from make-time-age effects (H_0: $\pi_{itv} = \bar{M}_v + \pi_{its}$ where $s = t - v$) is satisfied, we have

$$\log (P_{kitv}) = \bar{M}_v + \pi_{its} + \sum_{j=1}^{h} a_{tj}x_{kivj}$$

(9) If the hypothesis of no vintage-specific effect (H_0: $\bar{M}_v = 0$) is satisfied, we can write the hedonic equation as follows

$$\log (P_{kitv}) = \pi_{its} + \sum_{j=1}^{h} a_{tj}x_{kivj}$$

(10) If the hypothesis of the separability of the pure (hedonic) price index $\bar{P}_t$ from the make-age effects π_{is} (H_0: $\pi_{its} = \bar{P}_t + \pi_{is}$) is satisfied, we can write it as

$$\log (P_{kitv}) = \bar{P}_t + \pi_{is} + \sum_{j=1}^{h} a_{tj}x_{kivj}$$

This hypothesis can be restated as the hypothesis of constancy of the make-age effects over time. It implies the following two specific hypotheses:

(a) The constancy of make effects over time (H_0: $M_{its} = M_{is}$ for any t, where M_{its} is the make-effect of make i at time t and age s).

(b) The constancy of age effects (depreciation pattern) over time (H_0: $D_{its} = D_{is}$ for any t, where D_{its} is the age effect of make i of age s at time t).

(11) If the hypothesis of the separability of make-effects from age effects (depreciation pattern) (H_0: $\pi_{is} = M_i + D_s$) is satisfied, the hedonic equation reduces to

$$\log (P_{kitv}) = \bar{P}_t + M_i + D_s + \sum_{j=1}^{h} a_{tj}x_{kivj}$$

which is the typical regression equation to be used in the empirical sections below. This hypothesis (H_0: $\pi_{is} = M_i + D_s$) implies the following two subcases:

(a) The depreciation pattern is equal across makes (H_0: $D_{is} = D_s$ for any i, where D_{is} is the age effect of age s of make i).

(b) Make-effects are constant across all ages (H_0: $M_{is} = M_i$ for any s, where M_{is} is the make-effect of make i at age s). It asserts, in particular, the same structure of make-effects in the new and the used car markets.

(12) If the hypothesis of geometric depreciation in the used car market (H_0: $D_s = D_1 - \delta(s - 1)$, where s denotes age) is satisfied, then the hedonic equation can be written as follows

$$\log (P_{kitv}) = \bar{P}_t + M_i + D_1 - \delta(s - 1) + \sum_{j=1}^{h} a_{tj}x_{kivj}$$

This hypothesis still allows the transition between "new" and "used" car status to occur at a rate different from the common geometric depreciation rate in the used car market.

(13) If the hypothesis of geometric depreciation is satisfied for all ages including the transition from "new" to "used" of age 1 (H_0: $D_s = -\delta s$), we have

$$\log (P_{kitv}) = \bar{P}_t + M_i - \delta s + \sum_{j=1}^{h} a_{tj} x_{kivj}$$

Now, returning to hypothesis (10):

(14) If the hypothesis of geometric depreciation holds separately for each make in the used car market (H_0: $\pi_{is} = M_i + D_{i1} - \delta_i(s - 1)$ for $s \geq 1$, where $M_i \equiv \pi_{i0}$), then the hedonic equation can be written as follows [11]

$$\log (P_{kitv}) = \bar{P}_t + M_i + D_{i1} - \delta_i(s - 1) + \sum_{j=1}^{h} a_{tj} x_{kivj}$$

(15) If the hypothesis of equal geometric depreciation rates for all makes in the used car market (H_0: $\delta_i = \delta$ for any i) is satisfied, the equation is

$$\log (P_{kitv}) = \bar{P}_t + M_i + D_{i1} - \delta(s - 1) + \sum_{j=1}^{h} a_{tj} x_{kivj}$$

(16) If the hypothesis of equal depreciation rate from "new" to the "used status of age 1" holds for all makes (H_0: $D_{i1} = D_1$ for any i), then the equation can be written as follows

$$\log (P_{kitv}) = \bar{P}_t + M_i + D_1 + \delta(s - 1) + \sum_{j=1}^{h} a_{tj} x_{hivj}$$

Now, returning to hypothesis (11):

(17) If the hypothesis of no change over time in the imputed prices of physical characteristics (H_0: $a_{tj} = a_j$ for any t) holds, then the hedonic equation is

$$\log (P_{kitv}) = \bar{P}_t + M_i + D_s + \sum_{j=1}^{h} a_j x_{kivj}$$

This would occur if there were no changes in supply conditions and in tastes, or if such changes cancel each other out.

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[11] For the used car data, M_i and D_{i1} are perfectly collinear. M_i can be estimated, however, using the data on new car prices alone.

Return again to hypothesis (11):

(18) If the hypothesis of no make effects (H_0: $M_i = 0$ for all i) is satisfied, then the hedonic equation simplifies to

$$\log (P_{kitv}) = \bar{P}_t + D_s + \sum_{j=1}^{h} a_{tj}x_{kivj}$$

E. Criteria for Hypothesis Testing

Most of our hypotheses, such as the equality of imputed prices of physical characteristics across firms or years, can be tested using the standard F-test methodology. But such hypotheses are not the "truth." They are, at best, potentially useful approximations to it. The real world is, of course, much more complex. Having large samples and using standard tests, we are likely to reject most such simplifying hypotheses on purely statistical grounds, even though they may still serve as adequate approximations for our purposes.

The rejection or acceptance of a hypothesis should depend on the researcher's interests and his loss function.[12] If the researcher is interested in predicting price differentials, then he should be interested in the difference in fit between the unconstrained and constrained regressions. He should compare the standard errors of both regressions instead of following formal F tests and not reject the simpler hypothesis unless they are very different.

Since our hedonic regressions are semilogarithmic, the standard errors of the regressions measure the unexplained variation in prices in, roughly, percentage units. It is reasonable, therefore, to use the difference in the standard errors of the unconstrained and constrained regressions as a relevant measure of the price-explanatory power of a particular model. The standard errors of our regressions are about 0.1. Consider a difference in the standard errors of the constrained and unconstrained regressions of 0.01. It implies that: (i) the lack of fit of the constrained regression is increased by 10 per cent compared with that of the unconstrained regression ($0.01/0.1 = 0.1$). (ii) The fit to actual price data is smaller by 1 per cent in the constrained regression than in the unconstrained regression. This seems to us to be a just noticeable difference in our own measure of economic significance. We shall, therefore, not reject null hypotheses if differences between the standard errors of the unconstrained and the constrained regressions are less than or equal to 0.01. We will, however, list also the results of the formal F tests for the benefit of interested readers.

[12] See Arrow (1960) for an exposition of the difference between statistical (classical Neyman-Pearson) and economic significance (decision theoretic) tests, and Lindley (1963) and Leamer (1973) for a more recent exposition of this viewpoint from a Bayesian perspective.

III. SAMPLE, SOURCES, AND DEFINITIONS

Our sample consists of U.S. domestic four-door sedans and four-door hardtops of thirteen makes from the model years 1955 through 1971.[13] The thirteen makes are (1) American Motors, (2) Buick, (3) Cadillac, (4) Chevrolet, (5) Chrysler, (6) Dodge, (7) Ford, (8) Imperial, (9) Lincoln, (10) Mercury, (11) Oldsmobile, (12) Plymouth, and (13) Pontiac.[14]

We did not attempt to collect as many models as possible in each year as had been done in previous studies. Instead, we tried to keep the size and composition of the sample across makes representative and constant over time. We tried to keep the number of models in each make constant over time to avoid introducing shifts into our hedonic price indexes due to changes in the sample distribution across makes. Also, repeated observations on models with very similar physical characteristics increase computational costs without providing much additional information. We tried to get about 4 models per make on average (thus, about 52 models in each year), choosing models with high sales and as variable physical characteristics as possible. We chose high-sales models because they represent the automobile market better and also because these same models are included in our sample of used cars, and high sales provide some assurance of quality of data in the secondhand market. We tried to choose models whose production was above 10,000 units per year on the average.[15] Makes that have high sales and many models are represented by many models in our sample. The distribution of our sample across makes and the total sales of all included models are given in Table 1. Because of the proliferation of models, our sample increases slightly over time. It was difficult to obtain 4 models per make with significant variation in characteristics in the earlier years (especially 1955).

A major problem in such studies is the treatment of optional equip-

[13] We shall concentrate below on analyzing the 1961–1971 period. However, because 1955 to 1960 models appear in our used car prices analyses for 1961 and subsequent years, we also collected new price data for those years and included them in some of our analyses of new car prices.

[14] These are the major domestic makes. They are produced by the following four companies: American Motors Corporation (American Motors), Chrysler Corporation (Chrysler, Imperial, Dodge, and Plymouth), Ford Motor Company (Ford, Lincoln, and Mercury), and General Motors Corporation (Buick, Cadillac, Chevrolet, Oldsmobile, and Pontiac).

[15] *Ward's* provides detailed production data. In deciding on the particular model to include, we also paid attention to relative sales by engine type (6 cylinder or V-8). For example, Fury III had a large production for the V-8 model, but only a few 6-cylinder units were sold.

TABLE 1

Part 1: The Distribution and Average Sales per Sample Model

Vintage Year	1955	1956	1957	1958	1959	1960	1961	1962	1963
Number of observations	30	45	47	48	47	50	51	52	52
Number of observations for:									
$M1$	1	2	4	4	4	4	4	4	4
$M2$	6	5	6	6	6	6	6	6	6
$M3$	2	2	2	2	2	2	2	2	2
$M4$	2	4	4	4	4	5	5	6	6
$M5$	2	4	4	4	4	4	4	4	4
$M6$	3	5	5	5	5	5	5	5	5
$M7$	2	5	5	5	4	6	6	6	6
$M8$	1	1	1	1	1	1	1	1	1
$M9$	1	1	1	1	1	1	1	1	1
$M10$	2	3	3	3	3	3	3	3	3
$M11$	4	5	4	5	5	5	5	5	5
$M12$	2	4	4	4	4	4	4	4	4
$M13$	2	4	4	4	4	4	5	5	4
Average sales per sample model	212,320	123,629	117,601	83,191	82,011	93,019	83,966	102,070	110,343

(continued)

TABLE 1 (concluded)

Vintage Year	1964	1965	1966	1967	1968	1969	1970	1971	1955–1971
Number of observations	52	56	56	56	56	56	56	55	865
Number of observations for:									
$M1$	3	4	4	4	4	4	4	4	62
$M2$	6	6	6	6	6	6	6	6	101
$M3$	2	3	3	3	3	3	3	2	40
$M4$	6	6	6	6	6	6	6	6	88
$M5$	4	4	4	4	4	4	4	4	66
$M6$	6	6	6	6	6	6	6	6	91
$M7$	6	6	6	6	6	6	6	6	93
$M8$	1	1	1	1	1	1	1	1	17
$M9$	1	1	1	1	1	1	1	1	17
$M10$	3	3	3	3	3	3	3	3	50
$M11$	5	5	5	5	5	5	5	5	83
$M12$	4	5	5	5	5	5	5	5	73
$M13$	5	6	6	6	6	6	6	6	84
Average sales per sample model	105,164	110,517	104,808	94,400	105,497	105,690	86,706	96,625	–

Part 2: The Distribution of the Used Car Sample over Years and Makes

Year	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1961–1971
Number of observations	267	288	295	300	304	313	319	324	328	332	336	3,406
Number of observations for:												
$M1$	19	22	24	24	23	23	23	23	23	23	24	251
$M2$	35	35	36	36	36	36	36	36	36	36	36	394
$M3$	12	12	12	12	12	13	14	15	16	17	18	153
$M4$	23	26	28	30	32	34	35	36	36	36	36	352
$M5$	22	24	24	24	24	24	24	24	24	24	24	262
$M6$	28	30	30	30	31	32	33	34	35	36	36	355
$M7$	27	31	32	33	34	36	36	36	36	36	36	373
$M8$	6	6	6	6	6	6	6	6	6	6	6	66
$M9$	6	6	6	6	6	6	6	6	6	6	6	66
$M10$	17	18	18	18	18	18	18	18	18	18	18	197
$M11$	28	29	29	30	30	30	30	30	30	30	30	326
$M12$	22	24	24	24	24	25	26	27	28	29	30	283
$M13$	22	25	26	27	28	30	32	33	34	35	36	328
Vintage	1955–1960	1956–1961	1957–1962	1958–1963	1959–1964	1960–1965	1961–1966	1962–1967	1963–1968	1964–1969	1965–1970	1955–1970

NOTE: See the "Notes to Tables" at the end of this paper for the definition of M.

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ment such as power steering, air conditioning, and other attachments. While the main "body" of the car is well specified, much less information is available on such options, their prices, and the changes in their use.[16] We experimented at length with various treatments of optional equipment but there was no clear outcome. On the whole, the results were not very sensitive to the particular choice. Since they are described in detail in our larger manuscript, we shall not go into it here. In what follows, we shall use two price concepts interchangeably, though there is a clear conceptual difference between them. The first (PAA) includes the price of automatic transmission and power steering on all cars, while the second (PA) treats power steering as a "cost of weight and size" and includes it only on those cars where such equipment is "standard" and hence deemed to be required for adequate performance. Power brakes are treated as a cost of weight and included only on those models where they are standard equipment (this is true for both PA and PAA). Air conditioning is not included, heaters are included where the price information was available, and radios are included in used car prices and in new car prices when the latter are compared to used car prices.

List prices of new cars and used car prices are taken from the National Automobile Dealers Association (NADA) *Used Car Guide* (Central Edition), April issues (May in 1961), and were checked against the new car prices listed in the *Automotive News Almanac*. For the used cars part of our study, we did not use the data on cars that were less than a year old or more than 6 years old. Seven year old and older cars are not commonly traded in the organized part of the used car market and hence the quality of the data listed in the *Used Car Guide* for these cars is quite poor. Similarly, the market in cars less than a year old is also quite thin and the information base is not as firm as we would like it to be. Thus, for example, our sample in 1967 contains the list prices for the 1967 models and the used prices in April 1967 of the 1966, 1965, 1964, 1963, 1962, and 1961 vintage models.

We use the following standard set of physical characteristics which have been used with some success in previous hedonic studies:
(1) Shipping weight of the car in pounds (W)
(2) Overall length of the car in inches (L)
(3) Maximum brake horsepower in horsepower units (H)

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[16] See Griliches (1961), Triplett (1966), and Dewees (1971). The issue is discussed at great length in Ohta and Griliches (1972).

(4) Dummy for body type (*HT*)

$$HT = \begin{cases} 1 \text{ for the hardtop} \\ 0 \text{ for the sedan} \end{cases}$$

(5) Dummy for the number of cylinders (*V*)

$$V = \begin{cases} 1 \text{ for V-8} \\ 0 \text{ for the 6-cylinder engine} \end{cases}$$

The data on these physical characteristics are taken from the *Used Car Guide*.[17] They were checked against data listed in *Ward's* and *Automotive Industries* (March issue). The source and choice of performance characteristics will be discussed later, in Section V.

Several notes of warning should be sounded at this point. The treatment of optional equipment is somewhat arbitrary, but that doesn't seem to affect the results significantly. New car prices are "list" prices, not transaction prices. There may be differential discounting practices by makes which need not be stable over time. Used car prices are closer to the "transaction" concept, but the provenance and quality of these data are clouded by a lack of clear description of the methods used in collecting and editing them. Toward the end of the period, prices are affected by changes in excise taxes and new requirements for safety and antipollution equipment. All of this makes comparisons with published official price indexes difficult, a topic which we shall come back to below.

IV. RESULTS BASED ON PHYSICAL CHARACTERISTICS

A. New Cars

We shall skip over several important side issues and concentrate our analysis on make-effects and depreciation patterns. We did also experiment, however, with different functional forms, different definitions of the dependent variable, and different weighting schemes. As to functional form, we quickly settled on the semilogarithmic form for reasons of ease of comparison with earlier studies and somewhat better fit. Also, the choice of functional form was not the main focus of our inquiry. We did experiment at length with different treatments of optional equipment and, hence, different concepts of price but found little empirical evidence for preferring one treatment to another. Because of our careful choice of sample models to represent their dis-

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[17] The specific months of the *Guide* are the same as for the list price of the car stated before.

tribution in the total car market as closely as possible, it turned out that weighting by the square root of model sales leads to essentially the same results as the analysis of the unweighted but self-weighting samples. Hence, we report here only the latter results.[18]

Table 2 lists the results of adjacent year regressions for selected pairs of years between 1955 and 1971 and provides a representative sample of the results of our more extensive analysis of new car prices. They are similar to the Griliches (1961, 1964), Triplett (1966), and Dewees (1970) results for earlier years, except that including make-effects reduces somewhat the size of the weight coefficient, while at the same time increasing the size and statistical significance of both horsepower and length in such regressions. Make-effects are statistically and economically significant, their inclusion reducing the standard errors of the regressions from about .08 to .04. While there is quite a bit of instability in the coefficients of the primary physical characteristics (H, W, and L), there is no clear trend in these coefficients and the instability appears to be the result of multicollinearity between H and W and sampling fluctuation.

A formal statistical test of the constancy of the coefficients of the physical characteristics over time, utilizing pair-wise comparisons of 1962 and 1967 and 1961 and 1971, does not reject the null hypothesis at the 5 per cent significance levels (the computed F statistics are each approximately 2.3) and the standard errors of the constrained regressions are not increased by more than .004. We can, therefore, maintain the hypothesis that the coefficients (implicit price schedules) of physical characteristics did not change significantly between 1961 and 1971. It implies largely neutral shifts in supply conditions of these characteristics and the cancelling out of changes in consumer tastes, if any.

Dhrymes (1967) claimed that imputed prices of physical characteristics are significantly different among companies and concluded from his evidence that the valuation of physical characteristics is not based on consumers' preferences but rather on different markup pricing policies of different firms. We can introduce firm dummies (both in additive and in multiplicative form) to test the null hypothesis that relative imputed prices of physical characteristics are the same among companies.[19] Weighted regression should be used to reflect

[18] See Ohta and Griliches (1972) for more details on these and other issues.

[19] Given our emphasis on make-effects, we should also have tested the null hypotheses that imputed prices are the same across makes rather than just across companies. We did not do it because of the limitation of the computer program RAPFE, which was used for the analysis of the new car market.

the valuation of these characteristics by consumers in the new car market. The firms are American Motors, Chrysler, Ford, and General Motors. The value of the F statistic for the null hypothesis that imputed prices are the same across companies is 1.81 for 1955–1958 and 1.82 for 1959–1962.[20] Both values are only slightly larger than the critical $F_{.05}$ of about 1.75 but smaller than the critical $F_{.01}$ of about 2.20. Allowing also for multiplicative firm effects would only reduce the values of these test statistics further, because it would allow more degrees of freedom to the constrained regression. Moreover, the difference in the standard errors between the constrained and the unconstrained regressions does not exceed .003. It is reasonable, therefore, to consider the null hypothesis as not rejected.

Table 2 also lists the estimated make-effects with American Motors as the base. It appears that from about 1960 on, the estimated make-effects are reasonably constant, but that is not true for the pre-1960 period. This could be due to the smaller and poorer sample in those years and to the changing position of American Motors (which was used as a base) during those years. To get around the latter problem, we present in Table 3 rescaled make coefficients for selected years, with the major make, Chevrolet, as the base of comparison. These coefficients do not tell a very different story, indicating stability in the post-1960 period. Pair-wise tests of equality of make coefficients in 1962 and 1967, and in 1961 and 1971, do not reject the null hypothesis even at the .05 level, the standard error of the constrained regressions rising by less than .002. In discussing make effects we will, therefore, treat the whole 1961–1971 period as one unit.

Significant positive make-effects (compared to Chevrolet) are indicated in Table 3 for Cadillac, Imperial, and Lincoln in the post-1960 period. The make-effect of Plymouth appears to be negative throughout. The other make-effects were not consistent and/or significantly different from the Chevrolet level.

The Cadillac, Lincoln, and Imperial effects are roughly of comparable size (with Imperial having the smallest of the three effects), indicating an "overpricing" of about 35 per cent relative to Chevrolet (and other makes).[21] This is surprisingly large (about $1,500 in a $6,000 car). It appears that the hedonic approach, using the standard set of

[20] The results of tests allowing the imputed prices of the physical characteristics to vary over the different companies is reported only for 1955–1958 and 1959–1962. For other periods, the unconstrained regressions suffered from almost perfect multicollinearity.

[21] The median effect of these makes appears to be on the order of .3. Exp (.3) − 1 = .35 and 1/1.35 = .74.

TABLE 2

Adjacent-Year Regression with Make Dummies: Selected Years
(*PAA* as the price variable)

	1955–57	1958–59	1960–61	1962–63	1964–65	1966–67	1968–69	1970–71
H^*	0.023	0.049	0.138	0.111	0.116	0.069	0.085	0.072
	(0.96)	(1.89)	(7.12)	(6.23)	(5.95)	(4.34)	(5.99)	(3.96)
W^*	0.437	0.345	0.034	0.006	0.102	0.172	0.142	0.217
	(10.25)	(4.51)	(0.78)	(0.16)	(2.88)	(3.86)	(3.14)	(5.74)
L^*	0.050	0.072	0.040	0.049	0.021	0.007	0.022	0.015
	(3.51)	(2.71)	(2.27)	(3.85)	(1.64)	(0.50)	(1.55)	(1.19)
V	0.020	−0.006	−0.004	0.026	−0.010	0.002	−0.001	−0.014
	(1.15)	(−0.25)	(−0.25)	(1.86)	(−0.63)	(0.15)	(−0.09)	(−0.77)
HT	0.045	0.031	0.033	0.050	0.022	0.028	0.033	0.027
	(5.16)	(2.86)	(3.10)	(5.06)	(2.11)	(2.78)	(3.77)	(2.33)
$M2$	−0.309	−0.288	0.029	0.038	0.019	0.069	0.035	0.023
	(−8.53)	(−5.49)	(1.14)	(1.69)	(0.78)	(3.08)	(1.88)	(1.02)
$M3$	−0.158	−0.050	0.424	0.451	0.345	0.381	0.320	0.261
	(−3.00)	(−0.66)	(12.54)	(15.97)	(11.27)	(12.96)	(11.79)	(7.50)
$M4$	−0.124	−0.133	0.051	0.000	0.004	0.045	0.006	−0.032
	(−5.62)	(−3.38)	(1.81)	(0.01)	(0.18)	(2.24)	(0.35)	(−1.54)
$M5$	−0.230	−0.099	0.061	−0.003	−0.012	0.086	0.065	−0.005
	(−5.67)	(−2.14)	(1.76)	(−0.12)	(−0.46)	(3.34)	(2.76)	(−0.17)
$M6$	−0.184	−0.127	−0.005	−0.063	−0.054	0.011	0.026	−0.031
	(−5.93)	(−2.78)	(−0.16)	(−2.33)	(−2.39)	(0.51)	(1.20)	(−1.45)

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M7	−0.167	−0.117	0.015	−0.024	−0.002	0.049	0.027	−0.029
	(−7.27)	(−3.58)	(0.56)	(−1.02)	(−0.09)	(2.44)	(1.53)	(−1.40)
M8	−0.077	−0.075	0.324	0.303	0.250	0.305	0.286	0.189
	(−1.19)	(−1.00)	(7.79)	(8.65)	(6.26)	(7.36)	(8.72)	(4.56)
M9	−0.117	−0.038	0.567	0.554	0.411	0.306	0.290	0.242
	(−2.31)	(−0.45)	(12.19)	(13.73)	(8.87)	(5.84)	(6.69)	(5.27)
M10	−0.188	−0.275	0.004	−0.027	−0.022	0.028	0.013	−0.029
	(−5.97)	(−5.79)	(0.12)	(−0.98)	(−0.82)	(1.06)	(0.56)	(−1.12)
M11	−0.243	−0.218	0.055	0.026	−0.028	0.040	0.029	0.005
	(−7.01)	(−4.74)	(2.11)	(1.10)	(−1.11)	(1.77)	(1.49)	(0.21)
M12	−0.170	−0.090	−0.014	−0.082	−0.040	0.014	0.024	−0.034
	(−6.78)	(−2.53)	(−0.50)	(−3.12)	(−1.77)	(0.69)	(1.24)	(−1.61)
M13	−0.179	−0.180	0.050	0.012	−0.021	−0.006	−0.028	−0.043
	(−5.77)	(−4.14)	(1.77)	(0.49)	(−0.84)	(−0.26)	(−1.51)	(−1.92)
T_1	5.436	5.253	6.727	6.748	7.013	7.072	6.902	6.884
	(26.27)	(13.99)	(29.80)	(43.16)	(41.96)	(37.61)	(41.93)	(40.20)
T_2	5.453	5.246	6.744	6.737	6.988	7.089	6.913	6.942
	(26.20)	(13.77)	(30.02)	(42.66)	(41.73)	(37.46)	(41.85)	(40.80)
T_3	5.459	—	—	—	—	—	—	—
	(26.04)							
SSR	0.1676	0.1794	0.1652	0.1182	0.1357	0.1499	0.1064	0.1748
SEE	0.041	0.049	0.045	0.037	0.039	0.040	0.034	0.044
R^2	0.978	0.964	0.975	0.983	0.978	0.976	0.982	0.974

NOTE: In the above table, T_1, T_2, and T_3 stand for the year dummies in the order of time lapse. That is, T_1 is earlier than T_2. See the text and the "Notes to Tables" given at the end of this paper for definitions of the various symbols. Figures in parentheses are estimated *t* ratios.

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TABLE 3

Make-Effects in the New Car Market with Respect to Chevrolet:
Selected Years

Make	1955–57	1960–61	1965–66	1970–71
American Motors	.124	−.051	−.024	.032
	(5.62)	(−1.81)	(−1.10)	(1.54)
Buick	−.185	−.022	.026	.055
	(−6.45)	(−.87)	(1.22)	(2.87)
Cadillac	−.035	.373	.325	.293
	(−.77)	(10.30)	(11.09)	(9.50)
Chrysler	−.107	.010	.004	.028
	(−3.28)	(.34)	(.16)	(1.18)
Dodge	−.060	−.055	−.049	.001
	(−2.47)	(−2.38)	(−2.68)	(.07)
Ford	−.043	−.035	−.000	.004
	(−2.39)	(−1.82)	(−.01)	(.19)
Imperial	.046	.273	.242	.222
	(.81)	(6.53)	(5.58)	(5.88)
Lincoln	.007	.517	.307	.274
	(.15)	(9.88)	(5.55)	(6.43)
Mercury	−.064	−.047	−.021	.003
	(−2.59)	(−1.90)	(−.84)	(.12)
Oldsmobile	−.119	.005	−.017	.037
	(−4.39)	(.19)	(−.69)	(1.91)
Plymouth	−.046	−.065	−.032	−.002
	(−2.34)	(−2.84)	(−1.73)	(−.08)
Pontiac	−.055	−.001	−0.29	−.010
	(−2.25)	(−.04)	(−1.36)	(−.54)

NOTE: PAA as the price; unweighted regression. The values in parentheses are *t* statistics.

physical characteristics, fails to explain about a quarter of the price of high-priced cars. This conclusion is robust with respect to the different treatments of optional equipment and the use or nonuse of weights in the estimation procedure.

Since only Cadillac, Imperial, and Lincoln have very significant and consistently large make-effects, and since these three makes are at the upper range of the physical characteristics, the observed make-effects may merely reflect additional nonlinearity in the effect of physical

characteristics on price. To check on this, we included the squares of horsepower and weight in a regression for the combined 1967–1971 period. Although the estimated coefficient of the square of weight was significantly positive at the 1 per cent level, the make-effects of Cadillac, Imperial, and Lincoln changed only slightly and were still statistically significant and large (.27, .21, and .21 respectively). They do not appear, thus, to be caused solely by additional nonlinearities in the effect of physical characteristics on price.

Since the thirteen makes are produced by only four firms (American Motors, Chrysler, Ford, and General Motors), make-effects could be merely a reflection of firm effects at a more disaggregated level. Because firm dummies are sums of make dummies, we can easily test the null hypothesis that make dummies can be aggregated into firm dummies. To reduce the number of observations so that the null hypothesis is not rejected solely because of a large sample, we used the 1957–1958 and 1961–1962 regressions. The values of the test statistics for this hypothesis was 10 for 1957–1958 and 31 for 1961–1962. Since $F_{.01}(9, 76) = 2.7$, the null hypothesis is strongly rejected.

Makes which had large, positive, and significant effects (Cadillac, Imperial, Lincoln) did not lose their market position over time. Neither did Buick, Chrysler, and Oldsmobile, which had slightly positive make-effects during the same period. These effects are not pricing errors. They have lasted in the new car market, and we expect them also to persist in the used car market. Such make-effects should be subtracted from hedonic regression residuals before they are used to explain changes in market shares and should be allowed for in the construction of hedonic price indexes.

B. Used Car Prices

A major additional source of data on prices is the used car market. If we extend the hedonic hypothesis across the new and used markets, we gain a great deal of additional information. In particular, we can observe, in effect, today's and yesterday's models being sold concurrently. "Except" for aging effects, much of the problem of measuring quality change over time disappears when we have repeated observations on the price of a particular vintage. To measure quality change we have to assume that aging effects (depreciation patterns) are separable from the characteristics levels and are stable over time and make. These are testable hypotheses. Because depreciation patterns are also of some intrinsic interest, they form the second major focus of our study.

TABLE 4

Used Car Prices (log PAA): Pooled Regression with Constant Imputed Prices of Physical Characteristics and Constant Coefficients of Age and Make Dummies over 1961–1971

Variable		Estimated Coefficient	t Statistic
Constant		6.9662	232.01
1962		0.0235	1.80
1963		0.1430	10.95
1964		0.1449	11.13
1965		0.1465	11.27
1966		0.0959	7.40
1967		0.1087	8.38
1968		0.1153	8.88
1969		0.1436	11.07
1970		0.1244	9.58
1971		0.2511	19.37
Age 2		−0.2369	−26.37
Age 3		−0.5004	−55.47
Age 4		−0.7758	−85.55
Age 5		−1.0857	−118.71
Age 6		−1.4417	−154.72
Buick	(M2)	0.1933	13.78
Cadillac	(M3)	0.6449	32.27
Chevrolet	(M4)	0.1885	13.96
Chrysler	(M5)	0.1490	9.74
Dodge	(M6)	0.0231	1.77
Ford	(M7)	0.0457	3.44
Imperial	(M8)	0.3625	14.47
Lincoln	(M9)	0.4776	18.24
Mercury	(M10)	0.0142	0.91
Oldsmobile	(M11)	0.1815	12.67
Plymouth	(M12)	−0.0092	−0.68
Pontiac	(M13)	0.1619	11.65
$H*$		0.0510	5.19
$W*$		0.0838	7.27
$L*$		0.0	0.0
V		0.1155	11.59
HT		0.0831	13.15
SSR		80.0625	
SEE		0.160	
R^2		0.9259	
Number of observations		3,406	
Number of parameters		33	

NOTE: See "Notes to Tables" at the end of this paper for definitions of the various symbols.

Our analysis of the used car market is based on unweighted, semi-logarithmic regression equations. Table 4 provides an overview of the results, constraining all of the coefficients, except the time dummies, to be constant during the 1961–1971 period. Weight, horsepower, and the dummy variables for hardtop (HT) and V-8 (V) engine have nonnegative and statistically significant estimated coefficients. The estimated coefficient of length is practically zero. Table 5 presents more detailed adjacent-years regression results, allowing all of the coefficients to change over time. There is quite a bit of instability in the estimated coefficients, primarily in the rise of the horsepower coefficient relative to the weight and length coefficients, and in the decline, in recent years, in the age coefficients for the older cars in the sample. Relative to the new car price results, tabulated in Table 2, the main differences are in the lower estimate of the effect of weight and in the higher estimated effect of having a V-8 engine on prices in the used car market. The fit is significantly improved by letting some of the coefficients change over time (the SEE falls from about .16 to .10), but the improvement comes largely from allowing the age coefficients to change over time. The fluctuations in the coefficients of the physical characteristics appear to be due largely to multicollinearity, and constraining them alone to be constant over time is not very costly in terms of the overall fit of the estimated relation. Pair-wise tests of the hypothesis of constancy of the physical characteristics coefficients over time for the years 1962 and 1967, and for 1961 and 1971, yielded conflicting results. The hypothesis is not rejected for the first comparison [$F = 0.95$, critical $F_{.05}(5, 590) \simeq 2.2$] but is rejected for the second (estimated $F = 2.4$) comparison (1961 and 1971). The latter results may be due to too large a sample ($N = 603$); the standard error in the constrained regression rising only by .004. It appears that the imputed prices of physical characteristics did not on the whole change much or consistently over time.

The hedonic hypothesis assumes the existence of markets for "imaginary" physical characteristics, with physical characteristics of various models of different ages having the same relative prices. We test the null hypothesis that relative imputed price schedules of physical characteristics are the same across all ages and that the effect of aging is incorporated only in the age dummies. This hypothesis of independence of imputed prices from age is equivalent to the null hypothesis of equal depreciation patterns for the different physical characteristics. We test it separately for 1965 and 1971. The unconstrained regression is.

TABLE 5

Used Car Prices (log PAA): Adjacent-Year Regressions with Make Dummies

	1961–63	1963–64	1964–65	1965–66	1966–67	1967–68	1968–69	1969–70	1970–71
H^*	0.062	0.077	0.076	0.029	0.030	0.061	0.093	0.131	0.140
	(4.93)	(4.59)	(4.30)	(1.79)	(1.95)	(5.01)	(5.21)	(6.81)	(9.51)
W^*	0.052	−0.028	0.028	0.153	0.123	0.065	0.060	0.001	−0.013
	(1.90)	(−0.81)	(0.82)	(5.01)	(4.39)	(2.73)	(1.60)	(0.03)	(−0.37)
L^*	0.024	0.050	0.046	0.017	0.027	0.029	−0.006	−0.021	−0.026
	(2.26)	(3.63)	(3.37)	(1.44)	(2.54)	(3.19)	(−0.40)	(−1.40)	(−2.18)
V	0.075	0.089	0.089	0.109	0.123	0.115	0.112	0.119	0.098
	(5.74)	(5.27)	(5.25)	(7.30)	(9.13)	(10.39)	(6.74)	(6.59)	(6.85)
HT	0.091	0.100	0.106	0.099	0.086	0.073	0.061	0.057	0.061
	(12.73)	(10.45)	(10.38)	(10.31)	(9.32)	(9.49)	(5.35)	(4.71)	(6.46)
$Age\ 2$	−0.2625	−0.2629	−0.2528	−0.2432	−0.2254	−0.2206	−0.2314	−0.2398	−0.2426
	(−23.69)	(−18.24)	(−17.07)	(−18.35)	(−18.57)	(−22.03)	(−15.54)	(−15.10)	(−19.38)
$Age\ 3$	−0.5392	−0.5145	−0.5202	−0.5047	−0.4802	−0.4713	−0.4830	−0.4972	−0.5001
	(−47.70)	(−34.91)	(−34.52)	(−37.49)	(−38.93)	(−46.46)	(−32.22)	(−31.18)	(−39.89)
$Age\ 4$	−0.8304	−0.7650	−0.8057	−0.8063	−0.7625	−0.7414	−0.7419	−0.7427	−0.7566
	(−73.27)	(−50.26)	(−52.52)	(−58.67)	(−60.65)	(−71.64)	(−48.73)	(−46.16)	(−60.12)
$Age\ 5$	−1.1911	−1.1237	−1.0928	−1.1463	−1.1049	−1.0321	−1.0329	−1.0194	−1.0159
	(−105.59)	(−73.28)	(−70.10)	(−82.35)	(−85.93)	(−97.21)	(−66.25)	(−62.29)	(−80.17)
$Age\ 6$	−1.5195	−1.5581	−1.5887	−1.5211	−1.4711	−1.3747	−1.3460	−1.3423	−1.3245
	(−127.48)	(−102.04)	(−101.32)	(−108.73)	(−113.08)	(−126.00)	(−83.67)	(−79.89)	(−102.75)
$M2$	0.012	0.100	0.202	0.263	0.181	0.113	0.160	0.225	0.241
	(0.60)	(4.26)	(8.31)	(11.65)	(8.62)	(6.47)	(6.12)	(8.16)	(11.43)
$M3$	0.578	0.632	0.640	0.650	0.599	0.545	0.577	0.633	0.603
	(21.47)	(19.25)	(19.25)	(21.90)	(22.15)	(24.53)	(17.40)	(17.69)	(21.39)

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M4	0.129	0.143	0.206	0.205	0.130	0.088	0.139	0.204	0.193
	(6.87)	(5.69)	(7.96)	(9.02)	(6.35)	(5.32)	(5.75)	(8.12)	(10.04)
M5	0.047	0.042	0.080	0.155	0.111	0.057	0.102	0.136	0.135
	(2.07)	(1.42)	(2.63)	(5.67)	(4.49)	(2.83)	(3.48)	(4.36)	(5.59)
M6	-0.080	-0.133	-0.086	0.005	-0.018	-0.037	-0.001	0.051	0.084
	(-3.83)	(-4.91)	(-3.04)	(0.20)	(-0.81)	(-2.12)	(-0.05)	(1.89)	(4.08)
M7	-0.018	-0.042	0.014	0.042	-0.004	-0.027	0.014	0.051	0.057
	(-0.97)	(-1.70)	(-.56)	(1.82)	(-0.18)	(-1.62)	(0.59)	(2.01)	(2.98)
M8	0.331	0.304	0.331	0.334	0.277	0.266	0.292	0.309	0.280
	(10.36)	(7.72)	(8.22)	(9.14)	(8.13)	(9.33)	(6.77)	(6.56)	(7.57)
M9	0.351	0.498	0.552	0.537	0.522	0.472	0.399	0.417	0.403
	(10.93)	(11.96)	(12.63)	(13.33)	(13.66)	(14.48)	(7.93)	(7.51)	(9.33)
M10	-0.091	-0.097	-0.043	0.032	-0.001	-0.055	-0.031	0.022	0.050
	(-4.41)	(-3.53)	(-1.49)	(1.22)	(-0.03)	(-2.71)	(-1.04)	(0.70)	(2.01)
M11	0.093	0.108	0.175	0.243	0.155	0.076	0.090	0.119	0.155
	(4.83)	(4.46)	(6.86)	(10.34)	(7.08)	(4.22)	(3.37)	(4.22)	(7.20)
M12	-0.126	-0.150	-0.100	-0.016	-0.026	-0.050	-0.014	0.031	0.043
	(-6.50)	(-5.86)	(-3.71)	(-0.65)	(-1.20)	(-2.86)	(-0.55)	(1.18)	(2.17)
M13	0.102	0.098	0.161	0.225	0.134	0.064	0.111	0.138	0.097
	(5.08)	(3.77)	(5.98)	(9.26)	(6.02)	(3.52)	(4.16)	(4.92)	(4.52)
Constant	6.737	6.548	6.364	6.557	6.422	6.571	7.205	7.638	7.753
	(46.84)	(36.19)	(35.11)	(41.35)	(44.60)	(54.90)	(39.76)	(38.66)	(50.26)
YD_1	0.003	-0.001	0.002	-0.046	0.015	0.004	0.027	-0.019	0.127
	(0.42)	(-0.08)	(0.22)	(-5.90)	(2.10)	(0.70)	(3.11)	(-2.10)	(17.57)
YD_2	0.122	-	-	-	-	-	-	-	-
	(14.96)								
SSR	7.460	6.074	6.523	5.481	4.912	3.452	7.768	8.966	5.637
SEE	0.095	0.103	0.106	0.096	0.090	0.075	0.111	0.119	0.094
R^2	0.973	0.968	0.968	0.974	0.978	0.983	0.960	0.952	0.969

NOTE: See "Notes to Tables" at the end of this paper for definitions of the various symbols. Figures in parentheses are estimated t ratios.

$$\log\text{(Price)} = \text{Const.} + \sum_{i=2}^{6} d_i A_i + \sum_{i=1}^{6}\sum_{j=1}^{5} a_{ij}x_{ij} + u$$

where $x_{ij} = x_j$ if the sample model is of age i and 0 otherwise (see above for the rest of the notation). The constrained regression is:

$$\log\text{(Price)} = \text{Const.} + \sum_{i=2}^{6} d_i A_i + \sum_{j=1}^{5} a_j x_j + u$$

The value of the test statistic is 0.5 for 1965 and 1.2 for 1971, while the critical value of $F_{.05}(25, 300)$ is approximately 1.5. The null hypothesis is not rejected in either year, allowing us to consider imputed prices of physical characteristics as equal across age and the depreciation patterns as equal across physical characteristics.

Buyers of new cars and buyers of used cars may be different, however, and used and new cars may not be perfect substitutes. One way to see if they are good substitutes is to test if the relative imputed prices of physical characteristics are the same for used and new cars at the same point in time. This allows us also to test whether the price-setting firms in the new market evaluate physical characteristics of cars in the same way as do the consumers in the used market. Because our used car prices are for cars with radios in them, we also included radio prices in the new car prices for this comparison. We use cars of *Age* 2 and make the number of used cars comparable to the number of new cars. We choose *Age* 2, because it takes some time for consumers to evaluate these cars and because the data on older cars are less reliable. The null hypothesis of no difference in imputed prices in the two markets is tested separately for 1962, 1965, 1967, and 1971. The unconstrained regression is as follows.

$$\log\text{(Price)} = \text{Const.} + d_2 A_2 + \sum_{j=1}^{5} a_{0j}x_{0j} + \sum_{j=1}^{5} a_{2j}x_{2j} + u$$

where x_{0j} is x_j if the sample model is a new car and 0 if it is a used car of *Age* 2. The constrained regression is given by

$$\log\text{(Price)} = \text{Const.} + d_2 A_2 + \sum_{j=1}^{5} a_j x_j + u$$

The values of the test statistic for 1962, 1965, 1967, and 1971 are .5, 1.6, .8, and 2.7, respectively. Since the critical value of $F_{.05}(5, 100)$ is approximately 2.3, the null hypothesis is not rejected on statistical grounds for 1962, 1965, and 1967. It is rejected at the 5 per cent but not at the 1 per cent level for 1971. But even in 1971, the SEE in the

constrained regression increases only by .004. We may conclude, there-fore, that by and large, firms evaluate physical characteristics correctly in the sense that they do so in the same way as consumers, and that new and used cars are the same goods (perfect substitutes), differing only in the "quantity" of the good contained per market unit.

Table 6 presents estimated make-effects with respect to Chevrolet for the whole period (1961–1971) and for selected subperiods. They appear to be related, perhaps unsurprisingly, to the "price class" of a

TABLE 6

Make-Effects in the Used Car Market (Chevrolet as Base)

	1961–62	1966–67	1970–71	1961–71
American Motors	−.143	−.130	−.193	−.106
	(−6.09)	(−6.35)	(−10.04)	(−2.55)
Buick	−.126	.051	.048	.029
	(−5.24)	(2.89)	(2.70)	(.78)
Cadillac	.457	.468	.411	.504
	(13.42)	(17.97)	(15.42)	(9.17)
Chevrolet	0	0	0	0
Chrysler	−.057	−.019	−.057	−.041
	(−2.21)	(−.91)	(−2.74)	(−.93)
Dodge	−.181	−.148	−.109	−.171
	(−8.12)	(−8.76)	(−6.59)	(−4.71)
Ford	−.127	−.134	−.135	−.131
	(−6.72)	(−8.81)	(−8.63)	(−3.94)
Imperial	.257	.147	.087	.215
	(6.41)	(4.51)	(2.47)	(3.11)
Lincoln	.213	.391	.210	.390
	(5.31)	(9.63)	(4.83)	(5.02)
Mercury	−.208	−.131	−.143	−.171
	(−8.85)	(−6.83)	(−6.78)	(−4.11)
Oldsmobile	−.032	.025	−.038	.013
	(−1.38)	(1.29)	(−2.02)	(.34)
Plymouth	−.250	−.156	−.150	−.190
	(−12.19)	(−9.02)	(−8.92)	(−5.20)
Pontiac	−.028	.004	−.096	−.023
	(−1.28)	(.22)	(−5.38)	(−.64)
Average	−.015	.028	−.006	.024

NOTE: The figure in parentheses are *t* statistics.

particular make. High-priced makes (Cadillac, Imperial, and Lincoln) have the largest make-effects, while "low priced" makes (American Motors, Ford, Plymouth, Dodge, and Mercury) have negative make-effects (relative to Chevrolet). Cadillac and Plymouth have the largest (.5) and the smallest effects (−.27), respectively.

Since the estimated make-effects are based on price data, they measure the degree of "overpricing" compared to the "hedonically" estimated quality. But since our list of physical characteristics is unlikely to be complete, we interpret *systematic* pricing deviations as reflecting unmeasured aspects of quality rather than just pricing errors. Can we say something about the total quality level (measured plus unmeasured) of makes? One way to do so is to use stock data, i.e., registration data on each vintage of each make over the years and to calculate its average life expectancy from such data. A make with a longer life can be thought of as having a higher quality and/or a lower deterioration rate of this quality, scrapping occurring when quality (performance) falls below a certain minimum level. Table 7 lists estimated median lives for each make based on the 1953, 1954, and 1955 vintages and their registration rates over the next fifteen years. The median life for all makes was 10.5 years. Only Cadillac and Chevrolet had median lives one year longer than the average. The life of American Motors cars appeared to be 2 years shorter and the lives of Lincoln and Mercury models were a year shorter than the median. Except for Lincoln, this is consistent with our estimated make-effects.

Comparing the estimated make-effects in the new and used car markets we find that they are not too different in relative position and

TABLE 7

Median Life of Cars: Average for 1953–1955 Model Years

Make	Median Life (Years)	Make	Median Life (Years)
American Motors	8.5	Lincoln	9.5
Buick	10.5	Mercury	9.5
Cadillac	11.5	Oldsmobile	10.5
Chevrolet	11.5	Plymouth	10.5
Chrysler	10.5	Pontiac	10.5
Dodge	10.5		
Ford	10.5	Average	10.5

size. (Compare Tables 3 and 6.) The main difference is that the esti-
mated make-effects are much more widely spread out in the used
market than in the new market.

We test the rather stringent hypothesis that make-effects are the
same in the new and used markets. We computed such tests for the
1962, 1965, 1967, and 1971 cross sections. The values of the test
statistics are shown in Table 8. Since $F_{.01}(12, 300) \simeq 2.25$, the null
hypothesis is rejected at the 1 per cent level for all the years. But the
F values are not large for such sample sizes (about 350). Moreover,
the standard errors of the constrained regressions do not rise by more
than .0065. From a practical point of view, 'there is little reason to
reject the null hypothesis. It appears that, on the whole, make-effects
observed in the new car market persist in the used car market at
roughly similar orders of magnitude.

We look next at changes in make-effects with age, within the used
car market. We test the null hypothesis that make-effects are the same
at *Age* 1 and *Age* 6, with American Motors as the base at both ages.
This hypothesis is tested for 1964 and 1971. The values of the test
statistics for 1964 and 1971 are 6.8 and 2.9 respectively. Since the
critical $F_{.01}(12, 80)$ is about 2.4, the null hypothesis is rejected at the
1 per cent level in both years. Also, the standard errors of the con-
strained regressions rise by .0203 and .0103 in 1964 and 1971, respec-
tively. The null hypothesis is thus also rejected by our "economic sig-

TABLE 8

Test of Equality of Make-Effects in the New
and Used Car Markets (All Ages)

	(1)	(2)	(3)	(4)	(5)	(6)
1962	3.36	.0831	.0868	340	36	24
1965	5.05	.0933	.0998	360	36	24
1967	3.23	.0723	.0750	375	36	24
1971	2.86	.0864	.0889	391	36	24

NOTE:
(1): value of the test statistic (F value).
(2): standard error of the unconstrained regression.
(3): standard error of the constrained regression.
(4): number of observations.
(5): number of parameters in the unconstrained regression.
(6): number of parameters in the constrained regression.

TABLE 9

Estimated Coefficients of the Age Dummies; 1961–1971
Pooled, Differing Imputed Prices for Different Years

	Dependent Variable			
	PA [a]	*PAA* [a]	*PAD* [a]	*PAA* [b]
Age 2	−0.2516	−0.2501	−0.2536	−0.2544
Age 3	−0.4916	−0.4886	−0.4956	−0.4980
Age 4	−0.7529	−0.7478	−0.7600	−0.7626
Age 5	−1.0756	−1.0683	−1.0857	−1.0877
Age 6	−1.4395	−1.4273	−1.4505	−1.4522

NOTE: See "Notes to Tables" at the end of this paper for definitions of the various price concepts.

[a] With make dummies.

[b] Without make dummies.

nificance" criterion. It appears that depreciation patterns are not constant over makes. Nor, as we shall see below, are they constant over time.

Table 9 lists our estimated age coefficients using various price concepts and including and excluding make dummies. All the different versions produce roughly the same results. They are very similar to Ramm's (1971) earlier estimates. Returning to Table 5 we note that the age coefficients are smaller in the more recent years. A formal test of the statistical significance of the difference in the age coefficients in 1962 and 1967, and in 1961 and 1971, rejects the null hypothesis at the 1 per cent level (estimated F levels are 11 and 6.3 respectively, while the critical $F_{.01}(5, 600)$ is about 3). The change in the standard errors is not very large, however, only .006 and .003 for the 1962–1967 and 1961–1971 comparisons respectively.

We noted earlier that make-effects do not appear to be constant over ages. Table 10 gives more detail on the deviations of the age coefficients by makes from their average (for the pooled 1961–1971 regression). The only really significant deviations are the lower than average depreciation of Chevrolets and higher than average depreciation of Lincolns. This is not too different from the conclusions reached earlier by Cagan (1965) and Wykoff (1970).

Geometric (declining balance or exponential) depreciation is often

TABLE 10

Deviations from the Average Age
Coefficients: 1961–1971 Period

Make	*Age* 2	*Age* 3	*Age* 4	*Age* 5	*Age* 6
American	.0000	−.0232	−.0099	−.0817	.0231
Motors	(.00)	(−.35)	(−.13)	(−.28)	(.33)
Buick	.0104	.0387	.0354	.0346	.0481
	(.19)	(.72)	(.66)	(.64)	(.89)
Cadillac	.0048	−.0006	−.0011	.0082	.0414
	(.06)	(.01)	(−.01)	(.09)	(.48)
Chevrolet	.0949	.1366	.1926	.2378	.3250
	(1.73)	(2.44)	(3.44)	(4.17)	(5.60)
Chrysler	−.0030	.0002	−.0080	−.0069	−.0491
	(−.05)	(.00)	(−.12)	(−.10)	(−.73)
Dodge	−.0157	−.0197	−.0320	−.0386	−.0621
	(−.28)	(−.35)	(−.57)	(−.69)	(−1.09)
Ford	−.0150	−.0114	.0061	.0276	.0288
	(−.28)	(−.21)	(.11)	(.50)	(.51)
Imperial	−.0594	−.0743	−.1120	−.1071	−.1069
	(−.90)	(−1.12)	(−1.76)	(−1.62)	(−1.64)
Lincoln	−.0338	−.0702	−.1134	−.1720	−.2243
	(−.51)	(−1.07)	(−1.72)	(−2.15)	(−3.40)
Mercury	−.0075	−.0277	−.0278	−.0457	−.0539
	(−.01)	(−.36)	(−.37)	(−.60)	(−.70)
Olds-	.0181	.0460	.0528	.0629	.0596
mobile	(.31)	(.78)	(.89)	(1.07)	(.99)
Plymouth	−.0241	−.0309	−.0533	−.0511	−.1009
	(−.39)	(−.50)	(−.85)	(−.81)	(−1.58)
Pontiac	.0309	.0359	.0707	.0685	.0706
	(.54)	(.63)	(1.22)	(1.16)	(1.18)
Average	−.245	−.512	−.792	−1.104	−1.461

NOTE: Figures in parentheses are *t* statistics.

assumed in capital theory. We test the null hypothesis that depreciation is geometric for 1962, 1965, 1967, and 1971. The unconstrained regression equation is

$$\log (PAA) = \text{Const.} + \sum_{s=2}^{6} d_s A_s + \sum_{j=1}^{5} a_j x_j + u$$

where A_s is a dummy variable for age s. The constrained regression equation is

$$\log (PAA_s) = \text{Const.} - \delta(s - 1) + \sum_{j=1}^{5} a_j x_j + u$$

where s denotes age in years and PAA_s is a price of a used car of age s with automatic transmission and power steering. The null hypothesis of geometric depreciation is that $d_s = -\delta s (s = 2, 3, \ldots, 6)$. This is equivalent to the following linear hypothesis: $2d_2 = d_3$, $3d_3 = 2d_4$, $4d_4 = 3d_5$, $5d_5 = 4d_6$.

The test statistics are summarized in Table 11. Since $F_{.01}(4, 300) \approx 3.4$ and $F_{.05}(4, 325) \approx 2.4$, the null hypothesis is rejected at the 1 per cent level for 1962, 1965, and 1967, but not even at the 5 per cent level for 1971. However, the difference between the standard errors of the unconstrained and the constrained regression is less than .01 for all the years. Geometric depreciation is thus not too bad an assumption "on the average" although it may be rejected when the sample gets very large.

To check how our data deviate from the geometric depreciation pattern rejected for 1962, 1965, and 1967, we ran the following regression, for the 1962, 1965, and 1967 samples:

$$\log (PAA_s) = \text{Const.} - \delta(s - 1) + \sum_{s=3}^{6} d_s A_s + \sum_{j=1}^{5} a_j x_j + u$$

TABLE 11

Tests of the Geometric Depreciation Hypothesis

	(1)	(2)	(3)	(4)	(5)	(6)
1962	4.00	.1566	.1600	288	11	7
1965	3.66	.1569	.1597	304	11	7
1967	10.60	.1223	.1296	319	11	7
1971	0.60	.1230	.1227	336	11	7

NOTE:
(1): value of the test statistic (F value).
(2): standard error of the unconstrained regression.
(3): standard error of the constrained regression.
(4): number of observations.
(5): number of parameters in the unconstrained regression.
(6): number of parameters in the constrained regression.

TABLE 12

Estimated Deviations of Depreciation at Age *s* from the
Exponential Depreciation Path

Parameter	1962	1965	1967
δ	0.2853	0.2570	0.2185
	(9.06)	(8.32)	(9.44)
d_3	0.0273	0.0159	−0.0318
	(0.50)	(0.30)	(−0.79)
d_4	−0.0828	−0.0885	−0.0822
	(−0.99)	(−1.09)	(−1.34)
d_5	−0.1136	−0.1417	−0.1604
	(−1.00)	(−1.27)	(−1.92)
d_6	−0.2209	−0.2681	−0.3208
	(−1.52)	(−1.89)	(−3.02)

NOTE: The values in parentheses are *t* statistics of the estimates.

where d_s measures the deviation of depreciation at age *s* from the
exponential depreciation path. The relevant results are listed in Table
12. The only statistically significant deviation from the exponential
path occurs at *Age* 6 in 1967. All the other deviations are not signif-
icant at the 5 per cent level. Geometric depreciation is thus not too
bad a hypothesis. However, deviations from it are systematic. Actual
depreciation occurs at a faster rate with age.

Table 13 lists estimated geometric depreciation rates by makes for
the years 1962, 1965, 1967, and 1971. Most of the rates appear to
decline over time. Chevrolet has consistently the lowest rate of depre-
ciation, while higher priced cars (such as Cadillac, Imperial, and
Lincoln) appear to have an above average depreciation rate. How-
ever, these differences are not very consistent or significant. Letting
the average depreciation change over time, but constraining it to be
the same across makes, raises the standard error of the constrained
regression by only .006 (for the pooled 1962, 1965, and 1971 sample).

We also estimated depreciation patterns for the combined new and
used car price data set with largely similar results. The first-year de-
preciation rate was consistently higher than the depreciation rate in
the subsequent years, but the difference was not very significant,
either statistically or by our change in the SEE criterion. The overall
depreciation pattern that emerged is summarized in Figure 2. We can-

TABLE 13

Geometric Depreciation Rates by Make of Car

	1962	1965	1967	1971
American Motors	.3117	.3358	.2705	.2533
Buick	.3469	.2713	.2532	.2456
Cadillac	.3169	.2795	.2707	.2886
Chevrolet	.2684	.2259	.2463	.2258
Chrysler	.3149	.3177	.2854	.2717
Dodge	.3319	.3430	.2935	.2534
Ford	.2879	.2739	.2822	.2509
Imperial	.3077	.2742	.3280	.3232
Lincoln	.4342	.3051	.2684	.3306
Mercury	.3740	.3268	.2740	.2650
Oldsmobile	.3236	.2263	.2521	.2733
Plymouth	.3452	.3233	.2980	.2682
Pontiac	.3256	.2575	.2621	.2571
Average	.3299	.2893	.2757	.2694
Common rate [a]	.3280	.3086	.2786	.2561

[a] Constrained to be equal across makes.

not tell whether the larger first-year drop is real without having access to transaction prices in the new car market.

Differences across makes in the depreciation from new to used status (*Age* 1) are the result of transitory make-effects and differential price discounting in the new car market. It is interesting, therefore, to estimate new-to-used depreciation rates for the various makes separately.

To simplify our analysis, we assume that imputed prices of physical characteristics are the same in the new and used car markets and that depreciation is geometric. We want then to estimate d_{1i} ($i = 1, 2, \ldots, 13$) in the following combined equation for the new and used car markets

$$\log (PAA_{is}) = \sum_{i=1}^{13} b_{0i}M_i - \sum_{i=1}^{13} d_{1i}A_uM_i - \sum_{i=1}^{13} \delta_i(s - 1)A_uM_i + \sum_{j=1}^{5} a_jx_j + u$$

where *PAA* is the price of a car of make i and age s (including the price of a radio for both new and used cars); M_i is a dummy variable for make i; A_u is 1 if the model is used ($s > 1$) and 0 if it is new ($s = 0$); s

FIGURE 2

Typical Depreciation Path
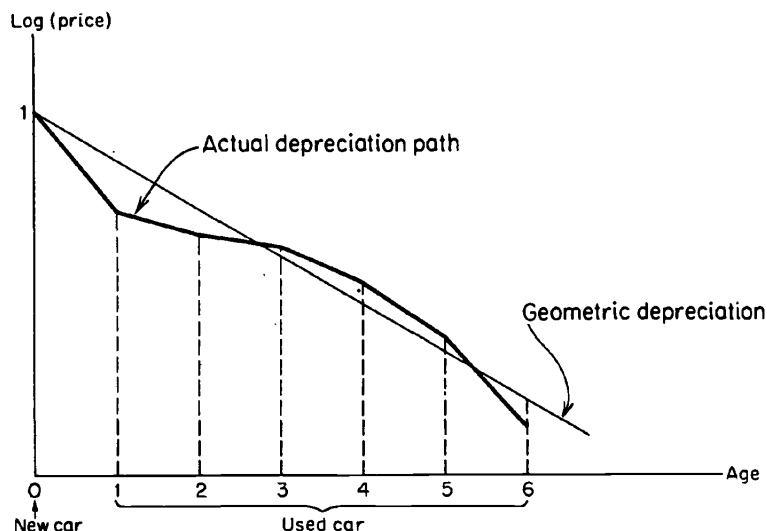
denotes age s ($s = 0, 1, \ldots, 6$). d_{1i} is the depreciation rate to *Age* 1 of make i. δ_i is the geometric depreciation rate of make i in the used car market. This equation is equivalent to the following set of two equations.

$$\log (PAA_{is}) = \sum_{i=1}^{13} b_{0i}M_i + \sum_{j=1}^{5} a_j x_j + u \qquad \text{if } s = 0$$

$$\log (PAA_{is}) = \sum_{i=1}^{13} b_{0i}M_i - \sum_{i=1}^{13} d_{1i}M_i - \sum_{i=1}^{13} \delta_i(s - 1)M_i$$

$$+ \sum_{j=1}^{5} a_j x_j + u = \sum_{i=1}^{13} b_{1i}M_i - \sum_{i=1}^{13} \delta_i(s - 1)M_i$$

$$+ \sum_{j=1}^{5} a_j x_j + u \qquad \text{if } s \geqq 1$$

where $b_{1i} = b_{0i} - d_{1i}$ and the imputed prices of the physical characteristics a_j are constant across the two equations.

Instead of computing the above regression with many parameters, we can estimate d_{1i} from our previous results. These estimates, shown in Table 14, indicate that low-priced makes (American Motors,

TABLE 14

Estimates of the Depreciation Rate from New to
Used Car Status (*Age* 1) for Each Make [a]

	1962	1965	1967	1971
Average rate $\hat{d}_1$ [b]	.3701	.2924	.3974	.4308
American Motors	.0317	.0731	.0240	.1707
Buick	.0002	−.0435	.0310	−.0286
Cadillac	−.1200	−.1544	−.1733	−.1849
Chevrolet	.0038	.0615	.0159	.0221
Chrysler	.0428	−.0365	.0601	−.0322
Dodge	.0838	.0006	.0640	.0277
Ford	.0363	.1359	.0770	.0705
Imperial	.0256	.0574	−.0743	−.0233
Lincoln	−.0675	−.1210	−.2557	−.0556
Mercury	.0018	.0274	.1089	.0375
Oldsmobile	−.0249	−.0533	.0530	−.0656
Plymouth	.0646	.0909	.0487	.0331
Pontiac	−.0781	−.0469	−.0255	.0290

[a] What is listed in the table are the deviations from the average depreciation rate $(\hat{d}_{1i} - \hat{d}_1)$ for each make.
[b] Constrained to be the same across makes.

Chevrolet, Ford, Plymouth) depreciate at a faster than average rate in the transition from new to used car status, as do Dodge and Mercury, while Cadillac and Lincoln depreciate at a much lower rate than the average car in the transition from new to used car status. The other makes do not show a systematic pattern over time. On the whole, high-priced makes depreciate at a lower than average rate in the first year, which may just reflect the fact that they are discounted less in the new car market.

We can combine our estimates of the first year depreciation rate and the estimates of the geometric depreciation rate for the other ages and consider the depreciation path over the whole life of a car, including the transition from the new to used, for each make separately. Looking at Tables 13 and 14 we note only a few significant deviations from the average: Cadillac appears to depreciate much less than average in the transition from new to used status but then continues to depreciate at the average geometric rate. Oldsmobile and Pontiac have a similar pattern, although their first-year depreciation is larger than that of Cadillac. Chevrolets have a slightly larger depre-

ciation rate in the first year but then they depreciate at a much lower geometric rate in the used market. Ford has a somewhat similar pattern, although its geometric depreciation rate in the used market is larger than that of Chevrolet. American Motors, Plymouth, Dodge, and Mercury show a slightly faster depreciation than average in the transition from new to used status but then continue to depreciate at the average rate or a slightly higher rate.

V. PERFORMANCE VARIABLES IN HEDONIC REGRESSION

We discussed earlier the following "two-stage hypothesis": Physical characteristics x of a good produce its performance levels y as outputs; physical characteristics are inputs into the cost function of the firm, but they do not enter the utility function of the consumer directly, only performance variables entering the latter. Previous hedonic studies have relied exclusively on physical characteristics variables to explain the variation in prices of important durable goods, such as automobiles, tractors, houses, refrigerators, turbo-generators, and boilers. Performance variables have not been used before as explanatory variables in hedonic regressions.[22]

Previous studies did not use performance variables because there was very little data on them, compared to the relative accessibility of data on the physical characteristics (specifications) of different goods.[23] We use the information on the performance of various automobile models given in the rating tables of *Consumer Reports*. We are interested in seeing if such variables perform as well in a hedonic regression as do the physical characteristics measures.[24] We would also like

[22] The R^2s are lower here.

[23] The situation may be changing for automobiles, as new safety regulations generate an entirely new set of data. See U.S. Department of Transportation, *Performance Data*, 1972.

[24] In our usage, "performance variables" are variables that are measured in some sense directly after the model is put on the market and are not derived simply from listings given by the manufacturer. We use tests and evaluations performed by the Consumers Union, an independent organization financed by consumers who buy its rating publications. It is possible, however, to proceed halfway and to construct "performance" variables out of physical characteristics, postulating a known transformation function from the first to the second stage. This is the procedure followed by Hogarty (1972) and Cowling and Cubbin (1972). The first study uses a "comfort" index which is the product of the sum of headroom and legroom times seatwidth and a "performance" variable which is the ratio of horsepower to weight. The second study uses a "passenger area" variable which is the product of "legroom" times "elbowroom." These can be thought of as a priori constrained versions of more general physical-characteristics-based regressions. Our accommodation or performance variables are based on scaled evaluations or actual tests, rather than on a direct transformation of listed specifications. It remains to be seen whether there is much gain in what we do. In any case, the Hogarty and Cowling and Cubbin studies are clearly a step in the right direction.

to know which performance variables are most significant in explaining the variation in car prices. Are they connected closely to specific physical characteristics, so that the latter would be good proxies for them in the hedonic regression? Can one think of performance variables as the output of a transformation function from physical characteristics to performance variables? Are there any performance variables that are not explained well by physical characteristics? Are the price indexes, make-effects, and depreciation patterns estimated using performance variables similar to those derived from estimates based on physical characteristics? A stable mapping from physical characteristics to performance variables would imply an affirmative answer to the last question.

Our sample is based on four-door U.S. sedans of 1963–1966 vintage that were rated by *Consumer Reports*. We use these ratings together with the prices of these cars in the used car market as of *Age* 1 through *Age* 6. The observation years and sample sizes are shown for each vintage in Table 15.

Our performance variables are derived from the results of road tests, ratings, and frequency of repair records given in *Consumer Reports*. Table 16 lists the performance variables used by us. Acceleration (AL), top speed (TS) and fuel economy (EC) are measured in specific (numerical) units defined in the notes to this table. The rest of the variables, such as handling (HL) or frequency of repair records ($R56$, $R66$, etc.), are given only qualitatively in the *Reports* and require scaling (or a long list of additional dummy variables). The scaling is to some extent arbitrary. It is described in detail in our manuscript (Ohta-Griliches, 1972) and will not be expounded here. It consists essentially of converting ratings such as excellent, good, or fair, or

TABLE 15

Performance Variables: Observation Years,
Vintage, and Sample Size

Vintage	Observation Years	Ages	Number of Models in Sample
1963	1964–69	1–6	16
1964	1965–69	1–5	20
1965	1966–71	1–6	33
1966	1967–71	1–5	35

TABLE 16

Performance Variables Available for each Vintage

1963	HL, ST, EN & PO, AT, RI, AC, TR, RE, R65, R66, R67, R68, R69, AL, TS, EC
1964	HL, ST, EN & PO, AT, RI, AC, TR, RE, R66, R67, R68, R69, AL, TS, EC
1965	HL, ST, EN, PO, AT, RI, AC, DE, RE, R66, R67, R68, R69, R70, R71
1966	HL, ST, EN, PO, AT, RI, AC, DE, RE, R67, R68, R69, R70, R71, BR

NOTE : Notations are as follows:

HL: handling, scale 0 to 8, from "fair" to "excellent."

ST: steering, sum of separate scales for manual and power steering, 0–7.

EN: engine, 0–5, 5 "very smooth and quiet."

PO: engine power, 0–2, 2 "high."

AT: automatic transmission, 0–5.5.

RI: Ride, 0–11.

AC: accommodation, 0–4.5.

TR: probable trade-in value, 0–5.

DE: probable dollar depreciation, 0–4.

RE: frequency of repair record of past models. Number of categories with better than average record minus the number of worse than average categories. (*RE* is used as the repair record in 1964 for the 1963 vintage and is used as the one in 1965 for the 1964 vintage.)

R65: Frequency of repair record reported in *Consumer Reports* in 1965.

R66, R67, . . . , R71: similar to *R65*.

AL: acceleration (time [seconds] required to increase the speed from 30 to 40 mph on 9% grade).

TS: top speed (mph) attainable on 9% grade.

EC: fuel economy (mpg at steady speed of 30 mph).

BR: brake, 0–7.

SOURCE: All performance variables are taken from *Consumer Reports: HL, ST, EN, PO, AT, RI, AC, TR, DE, RE*, and *BR* are taken from the *Rating* table. *R65, R66, . . . , R71* are from *Frequency-of-repair records. AL, TS*, and *EC* are from the *Road test*.

"very easy" to "heavy," to numbers running from 8, or 5, to zero, with larger numbers reflecting a more positive evaluation.

The ratings of cars in *Consumer Reports* are based on road tests and hence, strictly speaking, we should use only those particular models that were actually road tested. This was done for the 1963 and 1964 vintages. So restricted, we had only 16 and 20 models left, respectively. To enlarge the sample, we use all the models that are reported in the ratings section of *Consumer Reports* and were also included in our earlier, Section IV, sample. We get, this way, 33 and 35

models for the 1965 and 1966 vintages, respectively. Since *AL, TS,* and *EC* are available only for those models which were road tested, we do not have them for all of our sample models in these vintages. In place of *AL* and *TS*, we use *PO* separately from *EN & PO* for these (1965 and 1966) vintages.

The physical characteristics used in this section are again *H* (horse-power), *W* (weight), *L* (overall length) and *V* (dummy for V-8) and are the same as discussed in the earlier sections. So are also the new and used prices of these models.

If the cars tested and rated by *Consumer Reports* include optional equipment, then we add the price of those particular options to the price of the car. Since the ratings include automatic transmission on all cars in these vintages (1963–1966) so do our prices for the same models.

We concentrate on the analysis of used car prices in this section, because we expect *Consumer Reports* ratings to affect them much more than the list prices of new cars — if the ratings are correct and consumers are conscious of the particular qualities rated.

Since the rating criteria of *Consumer Reports* may not necessarily remain constant over time, first we analyzed each vintage separately. However, the results were not too different across vintages, and the range of models was too small to sustain an intensive investigation. We present, therefore, only the relevant test statistics from these regressions in Table 17, and list the coefficients for all the variables only for the combined 1963–1966 vintages regressions in Table 18.

From the viewpoint of fit, performance variables are quite success-ful in explaining car prices. They do about as well as physical char-acteristics or better. The standard errors are comparable to the stand-ard errors of the regressions reported in Section IV.[25] Statistics for formal tests of the null hypotheses that the coefficients of physical characteristics are all zero in the regression containing performance variables, and that the coefficients of performance variables are all zero in the regression containing physical characteristics, are listed in Table 17. The first null hypothesis is not rejected at the 5 per cent level for 1963, but it is rejected at the 1 per cent level for 1964, 1965, and 1966. The difference between the standard error of the uncon-strained regression and that of the constrained regression is more than 0.01 for the 1964 and 1966 vintages (the maximum difference is .024) but not for the 1963 and 1965 vintages. The second null hypoth-

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[25] These R^2's are lower, between .6 and .8, but that is due to the restricted range of these samples.

TABLE 17

Test of the Hypotheses that (A) the Coefficients of Physical
Characteristics are All Zero and (B) that the Coefficients of
Performance Variables are All Zero

Vintage	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1963	.111	.121	.155	96	21	17	10	1.35	8.43
1964	.060	.075	.075	100	20	16	9	13.13	5.73
1965	.099	.106	.116	198	20	16	10	7.08	7.63
1966	.075	.099	.093	175	20	16	9	26.75	8.40

NOTE:
    (1): standard error of the unconstrained regression.
  (2 & 3): standard error of the constrained regressions A and B, respectively.
    (4): number of observations.
    (5): number of parameters in the unconstrained regression.
  (6 & 7): number of parameters in the constrained regressions A and B, respectively.
  (8 & 9): the values of the test statistic (F value) for hypothesis A and B, respectively.

esis is rejected at the 1 per cent level for all the vintages. More-
over, the difference between the standard error of the unconstrained
regression and that of the constrained regression is more than 0.01
for all the vintages. Thus, both performance variables and physical
characteristics appear to be useful in explaining car prices, with
performance variables having a slight but inconclusive edge. Pooling
all the vintages reverses this conclusion, the regression with physical
characteristics and make dummies having a residual standard error
which is lower, but not by much (.012), than the comparable regres-
sion containing only performance variables.[26]

Let us look at the imputed prices of performance variables more
closely. Most of them are not statistically significant at conventional
significance levels. The correctly signed, significant performance
variables can be classified into two groups. The first group consists
of performance variables that are closely related to physical character-
istics. *AC* is highly correlated with weight. *PO* and *AL* are highly
correlated with horsepower. The second group consists of performance
variables which correspond to the depreciation rate (*TR* and *DE*) and
are correctly signed and significant in the absence of make-effects.
Performance variables that are not highly correlated with measured
physical characteristics are not statistically significant and often

  [26] The edge does not come from the "traditional" characteristics variables *H*, *W*, or
L, but from the significant dummy variable for V-8 engines.

TABLE 18

Pooled Regression of All the Vintages (1963–1966)
A: Performance Variables

Variable	With Make Dummies		Without Make Dummies	
	Estimated Coefficient	t Statistic	Estimated Coefficient	t Statistic
HL	0.003	0.74	0.009	2.74
ST	−0.007	−1.43	−0.001	−0.29
EN & PO	0.044	12.52	0.040	12.88
AT	−0.010	−2.22	−0.024	−6.22
RI	0.003	1.09	0.002	0.59
AC	0.011	3.49	0.023	8.57
TR (or DE)	−0.007	−1.09	0.022	5.40
RE	0.001	0.42	−0.000	−0.21
A_2	−0.2603	−14.23	−0.2445	−12.76
A_3	−0.5432	−24.18	−0.5107	−22.13
A_4	−0.8301	−30.07	−0.7807	−27.99
A_5	−1.1417	−34.55	−1.0763	−32.60
A_6	−1.4812	−36.71	−1.4083	−34.74
M2	0.1822	5.66		
M4	0.1644	5.32		
M5	0.2193	5.85		
M6	0.0459	1.68		
M7	0.0297	1.29		
M10	0.0482	1.61		
M11	0.0867	2.85		
M12	0.0281	1.04		
M13	0.1190	4.21		
T_1	7.2778	175.98	7.2681	179.23
T_2	7.2461	197.61	7.2273	204.90
T_3	7.2187	206.09	7.1768	211.97
T_4	7.2248	194.29	7.1687	195.47
T_5	7.2636	173.08	7.1911	170.98
T_6	7.3105	157.90	7.2228	154.56
T_7	7.3353	143.09	7.2273	139.47
T_8	7.5235	133.19	7.4037	129.29
Number of observations	569		569	
SSR	7.0929		8.0777	
SEE	0.115		0.121	
R^2	0.878		0.861	

NOTE: T_i is a dummy for year i ($i = 1$ for 1964, . . . , $i = 8$ for 1971); A_i is a dummy for age i; M_i is a dummy for make i. (M3, M8, and M9 are not in the sample. M1 is taken as the base make [i.e., its make-effect is 0].) Average make-effect is 0.0924.

TABLE 18 (concluded)

B: Physical Characteristics

$$\log (P) = \sum_{j=1}^{4} a_j x_j + \sum_{i=1}^{8} t_i T_i + \sum_{i=2}^{6} d_i A_i + \sum_{i=2}^{13} m_i M_i + u$$

Variable	With Make Dummies		Without Make Dummies	
	Estimated Coefficient	t Statistic	Estimated Coefficient	t Statistic
$H*$	0.026	1.17	0.057	2.62
$W*$	0.080	2.05	0.045	1.16
$L*$	0.002	0.15	0.023	1.88
V	0.153	8.71	0.124	6.62
A_2	−0.2585	−16.20	−0.2525	−14.12
A_3	−0.5373	−28.90	−0.5249	−25.48
A_4	−0.8198	−37.66	−0.8009	−33.63
A_5	−1.1266	−44.99	−1.1015	−40.61
A_6	−1.4555	−48.92	−1.4269	−43.96
$M2$	0.1558	6.77		
$M4$	0.1139	6.19		
$M5$	0.1053	3.27		
$M6$	0.0043	0.21		
$M7$	0.0010	0.05		
$M10$	−0.0124	−0.47		
$M11$	0.0708	3.09		
$M12$	0.0064	0.33		
$M13$	0.891	3.86		
T_1	7.1289	44.25	6.8418	43.94
T_2	7.1068	44.42	6.8175	44.26
T_3	7.0840	43.49	6.7866	43.46
T_4	7.0806	43.04	6.7771	43.06
T_5	7.1158	42.62	6.8060	42.68
T_6	7.1574	42.35	6.8417	42.45
T_7	7.1804	41.67	6.8571	41.80
T_8	7.3610	42.35	7.0328	42.54
Number of observations	569		569	
SSR	5.7155		7.3809	
SEE	0.103		0.116	
R^2	0.901		0.873	

NOTE : The average make-effect is 0.0534. See Table 16 and "Notes to Tables" at the end of this paper for definitions.

have wrongly signed coefficients. This may be the result of inappro-
priate scaling of the qualitative information on our part. Also, con-
sumers may not be very conscious of these particular qualities.

To test the two-stage hypothesis more explicitly, we look for two
things: (1) Is there anything left that can be explained by physical
characteristics in the residuals from the hedonic regression using
performance variables? (2) Are performance variables explained well
by physical characteristics?

The answer to the first question is already contained in Table 17,
examined earlier. Adding physical characteristics to the performance
variables regression does improve the fit somewhat, but not by much.
The standard errors of the individual vintage regressions drop by .01,
.015, .007, and .024 for the 1963, 1964, 1965, and 1966 vintages,
respectively. Thus, the regressions with performance variables do not
leave much to be additionally explained by physical characteristics
variables. The assumed causal direction (physical characteristics
produce performance variables and performance variables determine
prices) of the two-stage hypothesis seems not too poor a simplifica-
tion of what is clearly a more complex reality.

To answer the second question, we estimated linear transformation
functions of physical characteristics into performance variables.
Table 19 illustrates the results for the 1965 vintage. *PO* (power) is well
explained by horsepower and the V-8 dummy variable, and *AC* (ac-
commodation) is well explained by weight. The other performance
variables are not well explained (except for *EN* which is close to *PO*),
even by the combination of all the physical characteristics, but they
also have little power in explaining the variation in car prices.

Table 20 compares estimated age coefficients from Table 18 to those
estimated in Section IV (Table 4), based on the much larger sample of
used cars and their prices. There are no systematic differences in
depreciation patterns, whether we use performance variables or phys-
ical characteristics. All the differences are small. The depreciation
rate increases with age, but as before, the hypothesis of geometric
depreciation will be a good approximation to reality. We reestimated
our equations imposing the geometric depreciation assumption but
allowing the rate of depreciation to differ across makes. We shall not
report these results here, both for lack of space and because they were
not much different from the results reported earlier in Section IV.

Table 21 presents the estimated make-effects with Chevrolet as the
base and compares them to make-effects using physical characteristics,
both in the same sample, and in the larger sample of Section IV. They

TABLE 19

Performance Variables Related to Physical Characteristics: the 1965 Vintage
(number of observations = 33)

	HL	ST	EN	PO	AT	RI	AC	DE	RE
H	-0.015	-0.013	0.035	0.049	0.010	-0.022	-0.021	0.022	0.003
	(-0.72)	(-0.91)	(2.40)	(3.88)	(1.30)	(-1.19)	(-2.35)	(1.57)	(0.07)
W	0.004	0.002	-0.007	-0.002	0.000	0.005	0.008	-0.004	-0.002
	(1.13)	(0.80)	(-3.14)	(-1.18)	(0.20)	(1.71)	(5.75)	(-2.07)	(-0.31)
L	-0.035	-0.059	0.223	0.032	-0.018	-0.015	0.027	0.048	-0.021
	(-0.38)	(-0.95)	(3.47)	(0.58)	(-0.55)	(-0.19)	(0.69)	(0.77)	(-0.12)
V	0.067	0.380	0.447	4.016	-0.499	1.041	0.070	-0.776	0.188
	(0.04)	(0.36)	(0.42)	(4.33)	(-0.88)	(0.76)	(0.11)	(-0.74)	(0.06)
Constant	6.267	13.19	-22.30	-4.611	4.555	-2.498	-20.48	2.775	10.59
	(0.54)	(1.69)	(-2.78)	(-0.67)	(1.08)	(-0.24)	(-4.11)	(0.36)	(0.48)
R^2	0.092	0.101	0.551	0.922	0.148	0.358	0.913	0.265	0.047

NOTE: See Table 16 for definitions of the dependent variables. Figures in parentheses are t ratios.

TABLE 20

Estimated Age Coefficients in the Semilogarithmic
Regressions Using Performance Variables and
Physical Characteristics Respectively

	(1)	(2)	(3)
Age 2	−0.2603	−0.2585	−0.2369
Age 3	−0.5432	−0.5373	−0.5004
Age 4	−0.8301	−0.8200	−0.7758
Age 5	−1.1417	−1.1266	−1.0857
Age 6	−1.4812	−1.4555	−1.4417

NOTE:
(1): 1964–71 pooled regression with make dummies, all data,
performance variables.
(2): 1964–71 pooled regression with make dummies, all data,
physical characteristics.
(3): From Table 4. 1961–71 pooled regression with make dum-
mies, big sample, physical characteristics.

are very similar to each other, particularly those estimated from the
same sample. The largest difference, .056, occurs for Chrysler, but it
is not statistically significant. It does not appear to be the case that
make-effects estimated using physical characteristics can be explained
away by differential performance levels relative to characteristics
levels, at least not by the set of performance variables available to us.

Finally, let us look at the rate of the price decline of a car from new to
used status (*Age* 1) using performance variables. Let $\hat{Q} = EXP$
$\left(\sum_j \hat{b}_j y_j \right)$ be the estimated quality based on performance variables (y)
in the used car market. Let P_n and P_u be the new and used price (of
Age 1) of a car, respectively. If the firm overprices new cars from the
consumer evaluation viewpoint of $\hat{Q}$, then the price decline $(1 - P_u/P_n)$
from new to used status should be large. If the firm underprices it,
then the price decline will be small. The rate of underpricing by the
firm is measured by $\hat{Q}/P_n$. We are interested, therefore, in the coeffi-
cient α in the following equation

$$\log (P_u/P_n) = \text{Const.} + \alpha \log (\hat{Q}/P_u) + T_i + u$$

where α is the elasticity of the first-year depreciation coefficient with
respect to the quality-price ratio in the new car market and the T_i's

TABLE 21

Performance Variable Regressions with Comparisons:
Make-Effects with Respect to Chevrolet ($M4$)

Make	(1)	(2)	(3)
American Motors ($M1$)	−.164	−.114	−.106
	(−5.32)	(−6.19)	(−2.55)
Buick ($M2$)	.018	.042	.029
	(.74)	(2.09)	(.78)
Chrysler ($M5$)	.055	−.009	−.041
	(1.58)	(−.28)	(−.93)
Dodge ($M6$)	−.119	−.110	−.171
	(−3.97)	(−6.35)	(−4.71)
Ford ($M7$)	−.135	−.113	−.131
	(−5.55)	(−7.32)	(−3.94)
Mercury ($M10$)	−.116	−.126	−.171
	(−3.48)	(−5.36)	(−4.11)
Oldsmobile ($M11$)	−.078	−.043	.013
	(−3.15)	(−2.08)	(.34)
Plymouth ($M12$)	−.136	−.107	−.190
	(−4.48)	(−6.43)	(−5.20)
Pontiac ($M13$)	−.045	−.025	−.023
	(−1.82)	(−1.25)	(−.64)
Arithmetic average	−.072	−.061	−.079

NOTE :
(1): make-effects estimated in the pooled regression (1964–71) using performance variables.
(2): make-effects estimated in the pooled regression (1964–71) using physical characteristics.
(3): make-effects estimated in the pooled regression (1961–71) of the big sample of Section IV, using physical characteristics as the explanatory variables and PAA as the dependent variable.
The figures in parentheses are t statistics. Note that column (3) is not strictly comparable to columns (1) and (2), because the observation period and sample size are different.

are time-vintage dummies, allowing the overall price level to shift over time. We expect α to be positive. The results of such a regression for the combined 1963–1966 vintages sample is shown in Table 22. The estimated elasticity of P_u/P_n with respect to $\hat{Q}/P_n$ is positive, statistically significant, and on the order of .3. Adding TR (trade-in value) and make dummies to this regression does not change the results signifi-

TABLE 22

First Year Depreciation Related to the "Quality"–List-Price Ratio

Variable	Estimated Coefficient	t Statistic
$\log (\hat{Q}/P_n)$	0.2798	3.49
T_1	1.8215	3.00
T_2	1.8022	2.97
T_3	1.7463	2.89
T_4	1.7341	2.86
SSR	0.38262	
SEE	0.062	
R^2	0.109	

NOTE: Dependent variable $\log (P_u/P_n)$. $\hat{Q}$ is based on the coefficients of Table 18, not including make dummies.

cantly. Letting P_n have an independent coefficient (not constrained to equal $-\alpha$) raises the estimated α to 0.4 but reduces the estimate standard error by only .002. The unconstrained coefficients of $\hat{Q}$ and P_n add up to 1.14, implying a slightly lower price decline for larger and more expensive cars.

Price decline from the new to the used status of *Age* 1 may be affected more by the quality estimated in the new car market than by the quality estimated in the used market. Consumers could be using physical characteristics (x) rather than performance variables (y) to evaluate the qualities of cars. A year may be too short a time to gather adequate information about their performance. Hence we tried also $\hat{P}_n = EXP \left(\sum_j \hat{a}_j x_j \right)$ in place of $\hat{Q}$ in the above equation, where the $\hat{a}_j$'s are estimated physical characteristics coefficients in the earlier regression of new car prices. The estimated elasticity of P_u/P_n with respect to $\hat{P}_n/P_n$ is $\hat{\alpha} = .61$, larger than our estimate of this elasticity using $\hat{Q}$ as the measure of car quality. However, the fit of the two regressions is about the same, indicating no clear superiority for either $\hat{P}$ or $\hat{Q}$ in explaining P_u/P_n. This is consistent with our earlier acceptance of the two-stage hypothesis: both sets of variables tell largely the same story.

VI. HEDONIC PRICE INDEXES

This section will be relatively brief because we do not have the space, nor have we had the time, to explore the relevant issues adequately. The most interesting question, comparison with the official indexes, is hampered by lack of detailed description of the construction methods and specific adjustments made to these indexes.

We shall discuss our indexes in reverse order, starting with the small performance-variables sample, going on to the larger and most comparable used-car-prices sample, and concluding with a presentation of our new car price indexes and some comparisons.

Table 23 summarizes our comparisons for performance-variables-based versus physical-characteristics-based price indexes. The two tell largely the same story. The lack of significant discrepancies between the two (except perhaps for 1965–1966, for which period performance-variables-based indexes indicate a larger price decline) implies that there has been no significant progress in the transformation of physical characteristics into performance variables, or perhaps more correctly, that we have not been able to detect any, given the fragmentary data at hand.[27]

Table 24 summarizes the price indexes derived from our used car regressions, indicating that there is some difference, though not much, that arises from the treatment of optional equipment such as power steering. If one treats some of the increase in the use of power steering as a "cost of weight," then the constant quality price of used cars has gone up by more than is measured by indexes that link out such changes. (Compare the results for *PA* versus *PAA* or *PAD* in Table 24.) Also, allowing for make-effects results in a slower-rising index. Since the CPI does not go across makes in constructing its price index of used cars and tries to link out such changes as the increased use of power steering, the appropriate comparison for it is our *PAA* with make-effects-based index.

[27] Our sample is too small to be conclusive on this point. We have only 4 vintages (1963–1966) with a relatively small number of models each to derive price indexes for 8 years (1964–1971). A constrained price index, without make dummies, based on performance variables shows 6.5 percent less price increase than one based on physical characteristics for 1964–1971. This suggests that there may have been some progress in the transformation process over time. Constrained indexes without make dummies may be more accurate here, because our sample is too small to obtain reliable adjacent-year regression results (hence chain indexes). Also, because the sample composition was not kept constant, make dummies may absorb some of the price changes. More data for more models and vintages are needed to answer this important problem (i.e., the bias of hedonic price indexes based on physical characteristics, as compared with those based on performance variables).

TABLE 23

Annual Percentage Changes in Different Chain Price Indexes of Used Passenger Cars in the U.S.: Based on Adjacent-Year Regressions

Year	(1)	(2)	(3)	(4)	(5)	(6)
1964–65	−1.0	−4.0	−1.9	0.2	−0.2	2.5
	(2.4)	(2.6)	(1.8)	(0.9)		
1965–66	−6.1	−5.9	−2.0	−4.5	−2.7	−6.2
	(1.9)	(1.7)	(1.4)	(0.8)		
1966–67	−1.4	−0.0	−0.3	1.5	1.2	−0.4
	(1.5)	(1.3)	(1.0)	(0.7)		
1967–68	2.6	4.3	3.1	0.4	6.3	9.8
	(1.7)	(1.6)	(1.3)	(0.6)		
1968–69	4.8	6.6	4.1	2.8	3.9	−4.5
	(2.3)	(2.2)	(1.9)	(0.9)		
1969–70	−1.3	0.8	−2.0	−1.9	−7.6	−3.4
	(3.3)	(3.3)	(2.4)	(0.9)		
1970–71	20.1	16.4	14.6	13.6	10.1	8.9
	(5.3)	(5.5)	(2.6)	(0.7)		
1964–71	16.9%	17.6%	15.5%	11.7%	8.1%	8.4%

NOTE:
(1):   based on performance variables, without make dummies.
(2):   based on performance variables, with make dummies.
(3):   based on physical characteristics, with make dummies.
(4):   chain index from Section IV regressions (physical characteristics, with make dummies, *PAA* as the price).
(5):   CPI of used cars as of April of each year.
(6):   CPI of used cars, January-March average.
The figures in parentheses are standard errors.

Table 25 takes a closer look at the *PAA* (with make-effects) index and compares it to Ramm's (1971) estimates and the CPI index of used car prices. Note that we used April issues of the *Used Car Guide* for 1962 through 1971 and the May issue for 1961. Since the April issue is published at the beginning of April, our indexes are probably based on data collected in March and February. Hence, we have listed annual changes in the CPI for the January-March average, as well as for April. For the 1961–1962 comparison, we used the April and May indexes of the CPI, respectively. Large price increases occurred before

TABLE 24

Used Cars: Chain Hedonic Price Indexes and the Consumer Price Index (1962 = 100.0)

	(1)	(2)	(3)	(4)	(5)	(6)
1961	99.7	99.7	99.7	99.2	89.7	88.4
1962	100.0	100.0	100.0	100.0	100.0	100.0
1963	113:1	112.6	113.2	113.4	101.8	102.5
1964	112.8	112.5	113.0	114.9	106.6	110.4
1965	112.3	112.7	112.3	116.7	106.3	113.1
1966	106.6	107.7	106.5	112.5	103.5	106.1
1967	108.5	109.3	108.1	115.0	104.8	105.7
1968	112.2	109.8	107.4	116.0	111.4	115.3
1969	115.3	112.8	110.5	119.1	115.7	113.6
1970	113.2	110.6	107.7	116.6	106.9	109.8
1971	127.8	125.7	121.2	132.0	117.7	119.6

NOTE: Chain indexes are based on *Used Car Guide;* May issue for 1961, April issue for 1962 through 1971.
  (1): *PA* with make-effects.
  (2): *PAA* with make-effects.
  (3): *PAD* with make-effects.
  (4): *PAA* without make-effects.
  (5): *CPI* Index of Used Cars as of April of each year.
  (6): *CPI* Index of Used Cars, January-March average (except for 1968, where January-February average is used).

1963 and after 1970. Between 1963 and 1970 there was little overall price change. We pooled the data for 1963 and 1970 to check the statistical significance of a time dummy coefficient for 1970. The estimated coefficient is -0.032 ($\hat{t} = -3.4$) with make dummies, with 600-plus degrees of freedom. The price change is statistically significant but negative, and its absolute value quite small.

Discrepancies between our indexes and the other two occur in 1961–1962, 1962–1963, 1967–1968, and 1969–1970. In 1961–1962, both Ramm's index and the CPI show a large price increase but ours does not. On the other hand, our index shows a big increase in 1962–1963 when the other two do not. This may be due to a discrepancy in the timing of the various indexes. In 1967–1968, our indexes do not show any significant change while the two other indexes show a somewhat large price increase. On the whole, our index is closer to the CPI than Ramm's. Both our index and the CPI index show a large price

TABLE 25

Annual Percentage Changes in Price Indexes of U.S. Used Passenger Cars: 1961–1971

Calendar Year	Our Index (1)	Ramm (2)	CPI April (3)	CPI January-March average (4)
1961–62	0.3 (0.8)	17.2	9.4	13.1
1962–63	12.6 (0.8)	1.6	1.8	2.4
1963–64	−0.1 (0.9)	2.8	4.8	7.7
1964–65	0.2 (0.9)	0.4	−0.2	2.5
1965–66	−4.5 (0.8)	−12.1	−2.7	−6.2
1966–67	1.5 (0.7)	10.8	1.2	−0.4
1967–68	0.4 (0.6)	5.8	6.3	9.8
1968–69	2.8 (0.9)	N.A.	3.9	−4.5
1969–70	−1.9 (0.9)	N.A.	−10.0	−3.4
1970–71	13.6 (0.7)	N.A.	10.1	8.9
1961–68	14.4%	26.8%	22.1%	30.4%
1961–71	26.1	N.A.	26.4	35.2

NOTE: N.A. = not available.

(1): chain index based on adjacent-year regressions with PAA (with automatic transmission and power steering for all the models) as the dependent variables and with make dummies. Figures in parentheses are standard errors.

(2): chain index in column (1) of Table XIII of Ramm (1971): based on May-June issue of *Red Book National Used Car Market Reports* (Chicago: National Market Reports, Inc.).

increase from 1970 to 1971. On the other hand, we do not show as large a price decline in 1969–1970 as the CPI. Since our indexes and the CPI have been based on the same data base, we assume that discrepancies between our indexes and the CPI come from differential treatment of quality adjustments, optional equipment, and differences in the actual timing of the collected data.[28]

Our new car price indexes results are summarized in Table 26 with additional information to be gleaned from the earlier Table 2. There is little difference in results for the various versions in the post-1961 period. Weighting and the treatment of power steering make little difference to the final story. Including make-effects does, but the discrepancy is large for only the earlier part of the sample, where sample size is smaller and more variable from year to year. For the 1955 to 1960 period, our indexes, with make dummies and without, bracket Griliches' (1961) earlier estimates, which did not use make dummies but were based on a somewhat larger sample. For 1960–1965, our indexes with make dummies are significantly below, while those without are rather close to Triplett's (1969) price indexes for the same period.[29]

Comparisons with the CPI index of new car prices are hazardous because of a long list of different factors of unknown magnitude which could account for the observed discrepancies, the major ones being list versus transaction prices, differential methods of adjusting for quality change, different treatment of changes in warranties, and different treatment of safety and pollution abatement equipment. We shall concentrate on the 1961 to 1971 comparison, and our index (2) (*PA*, weighted, with make dummies) which is our best estimate of what might actually have happened. Figure 3 plots the two indexes (and the comparable used car price indexes). There is little difference between the two over the 1961–1971 period, both indexes rising rather consistently since the mid-sixties. The rate of increase since 1969 has been somewhat less for the CPI than in our estimated hedonic price index of new cars. This may be related to a substantial increase in the rate of "quality adjustment" by the Bureau of Labor Statistics (BLS), including such items as safety equipment and antipollution devices, which are costly to manufacture but are not necessarily a quality improvement from the point of view of the consumer.

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[28] The −10 per cent, +10 per cent changes in 1969–1970 and 1970–1971 shown by the CPI are not very credible. The methods of constructing the used car component of the CPI are not very satisfactory (see U.S. BLS, 1967) and recently there have been some procedural changes made to improve matters.

[29] See Ohta-Griliches (1972) for more detailed comparisons.

TABLE 26

New Cars: Chain Hedonic Price Indexes and the
Consumer Price Index (1962 = 100.0)

Model Year	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1955	95.6	93.5	84.0	83.2	91.3	82.3	6
1956	97.7	96.4	89.1	88.5	90.5	83.1	6
1957	98.0	97.8	92.7	92.2	95.1	93.4	6
1958	96.2	96.2	91.6	91.2	99.2	95.1	6
1959	95.1	95.1	91.8	91.2	103.3	100.9	6
1960	95.8	95.6	92.6	92.2	103.4		
1961	97.4	97.0	95.8	95.5	99.6		
1962	100.0	100.0	100.0	100.0	100.0		
1963	98.8	98.9	100.0	100.0	99.9		
1964	97.5	97.7	99.3	99.3	99.3		
1965	95.0	95.4	·96.6	96.4	98.7		
1966	96.1	96.6	97.9	97.8	94.5		
1967	97.5	97.8	99.9	100.2	95.6	96.0	7
1968	100.5	100.7	102.4	102.9	97.6	100.5	7
1969	101.5	101.5	103.6	104.4	99.9	103.3	7
1970	103.9	103.4	105.1	106.0	·101.1	105.3	7
1971	110.5	110.4	110.4	111.2	106.2	111.4	7

NOTE:
(1): *PA*, unweighted regression with make dummies.
(2): *PA*, weighted regression with make dummies.
(3): *PA*, unweighted regression without make dummies.
(4): *PDD*, unweighted regression without make dummies.
(5): November of previous year index of CPI.
(6): CPI adjusted for error in linking-in discounting, based on Triplett (1971), p. 28.
(7): Linked out "safety" and "exhaust emission" adjustments added back in, *approximately*, on the basis of scattered Wholesale Price Index (WPI) and CPI releases.

There is a rather large difference between the movements of the used car and new car price indexes. Used car prices rose significantly above new car prices in the early 1960s and then paralleled, very roughly, the movement in new car prices over time. On the whole, used car prices fluctuate more than new car prices, which is not surprising, and the CPI used car price index fluctuates more than the hedonic price index computed by us. There are at least two puzzles here: (1) Why did used car prices rise relative to new car prices in

FIGURE 3

Alternative Automobile Price Indexes

Index (1962=100)

Used cars, Hedonic

Used cars, CPI

New cars, Hedonic

New cars, CPI

Model year
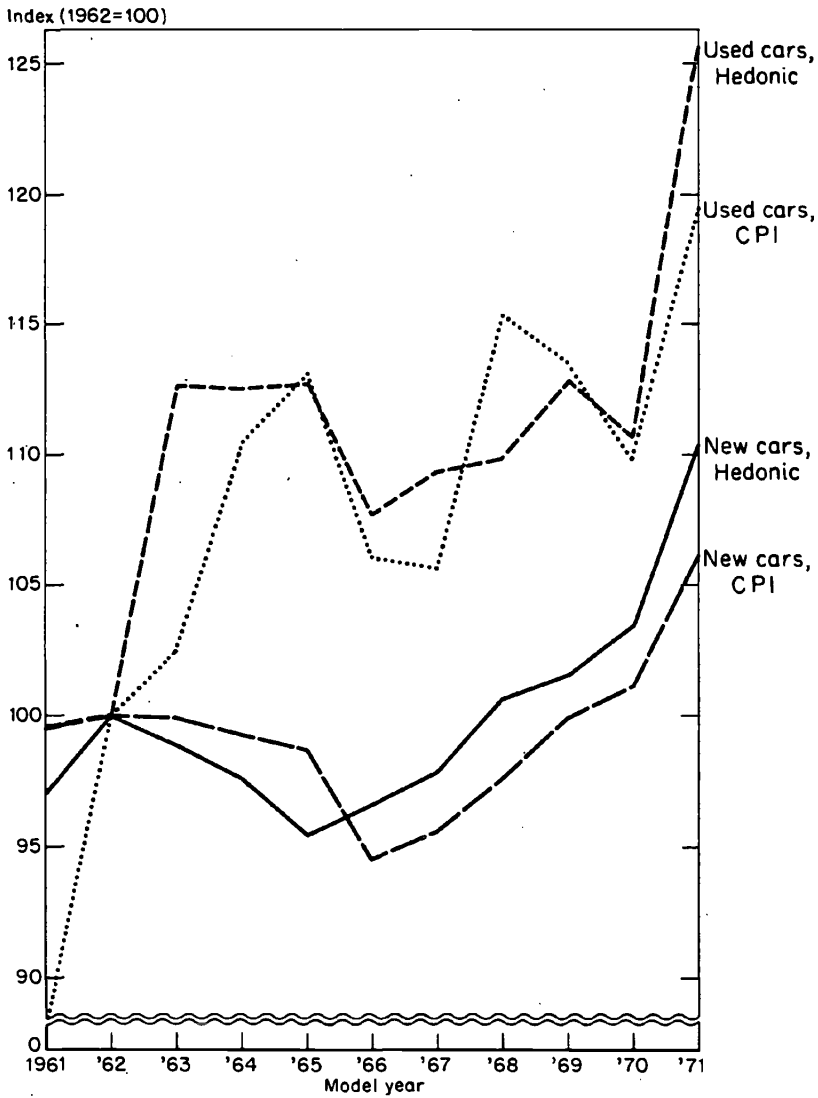
SOURCE: Table 24, columns 2 and 6; Table 26, columns 2 and 5.

the early 1960s? A possible interpretation is that the actual quality of new cars was falling in this period, the observed fall in new car prices not being "real" after all, and the used market reflecting the resulting appreciation of older cars.[30] (2) The used car component of the CPI drops sharply in 1969–1970 in the face of rising new car prices. Why? We need to know more about how the official indexes are actually constructed to be able to answer such questions and evaluate the various indexes.[31]

VII. SUMMARY

We have found some support for our "two-stage hypothesis," implying that there is little to be gained, at least given the currently available fragmentary data base, from moving away from physical characteristics to performance variables. We have also found that the declining balance (geometric) depreciation assumption is an adequate approximation for index number construction, but that depreciation rates appear not to be constant across time or makes. We found quite large make-effects, which we have not been able to explain away successfully. We also found that the new and used car markets can be analyzed jointly successfully, but that there have been shifts over time in the relative quality of new cars and the rate of depreciation of old ones, resulting in changing units of constant quality services per car between the new and used markets. These changes could use more analysis. So could the discrepancies between the price indexes

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[30] We should have run our used car price analyses allowing for vintage effects. Not having done so, we cannot really answer this question at the moment.

[31] The construction of the CPI new car price index can be gleaned from the articles by Larsgaard and Mack (1961), Stotz (1966), and subsequent BLS releases. Differences that would have to be evaluated are: (1) coverage (we cover a broader range of cars than the CPI), (2) transaction versus list price, (3) differences in methods of adjusting for quality change and in the range of such adjustment, (4) differences in the concept of "quality," and (5) differences in the treatment of conditions of sale such as warranties. The construction of the CPI used car price index is described in some detail in BLS (1967). Until recently in constructing this index the BLS used data supplied to it by the National Automobile Dealers Association, which also form the base for the *Used Cars Guide* figures. We differ from the CPI index of used cars in (1) coverage (only Chevrolets, Fords, and Plymouths were priced by the CPI before 1962, and only Chevrolets and Fords were priced between 1962 and 1967, when the above mentioned article was written), (2) treatment of optional equipment (no allowance was made for it before 1966), (3) allowance for quality change (none in the CPI), (4) treatment of depreciation (linear interpolation of an annual rate), and (5) unknown discrepancies in the timing of the underlying data. It is our opinion, that whatever the merits of our indexes, they constitute a significant improvement on the CPI *Used Car Price Component Index*. In the case of the *New Car Price Indexes*, the discrepancies are smaller and harder to evaluate.

computed by us and the comparable official indexes. In particular, we could, and hope to do so in the future, analyze whether "quality" adjustments made by the CPI in new car prices are recognized by consumers and validated in the used car market.

Given the recent (fall 1973) worldwide developments, many of the specific findings listed above are by now obsolete. The sharp rise in fuel prices has led and will lead to a substantial revaluation of the desired characteristics of automobiles. The curse of "you should live in interesting times" having caught up with us, we should use the methodology developed above to observe and analyze the coming changes in these markets.

NOTES TO TABLES

(1) Physical characteristics

H: maximum brake horsepower.
W: shipping weight (pound).
L: overall length (inch).
V: = 1 if the car has a V-8 engine; = 0 if it has a 6-cylinder engine.
HT: = 1 if the car is a hardtop; = 0 if it is not.
x_j: level of the jth physical characteristic ($j = 1, \ldots, 5$) (x_1 for H, x_2 for W, $\ldots$, x_5 for HT).

(2) Prices and dummies for options

P: list price of a car including the prices of standard equipment (except air conditioners).
PS: list price of power steering.
AT: list price of automatic transmission if it is not standard; = 0 if it is standard.
D_0: = 1 if power steering is an option; = 0 if it is standard.

$$PAA = P + AT + PS \cdot D_0$$

$$PAD = P + AT - PS \cdot (1 - D_0)$$

$$PA = P + AT$$

$$PDD = P - \max_i (AT_i) \cdot \overline{AT} - PS \cdot (1 - D_0)$$

where $\max_i (AT_i)$ is the maximum price of automatic transmission in that year over all models on which it is optional; $\overline{AT}$ is 1 if AT is 0 and is 0 if it is not.

(3) Used cars

PA: average retail price of a used car (including the price of automatic transmission for all the models but the price of power steering only for the models whose prices include it in the *Used Car Guide*).

PS: $\begin{cases} \text{average retail price of power steering for the used car.} \\ \text{list price of power steering for the new car.} \end{cases}$

D: dummy for the model whose price includes power steering in the *Used Car Guide*.

$$PAA = PA + PS \cdot D$$

$$PAD = PA - PS \cdot (1 - D)$$

T_i: dummy for vintage year i ($i = 1$ for 1955, $i = 2$ for 1956, . . . , $i = 17$).
Y_j: dummy for calendar year j ($j = 1$ for 1961, $j = 2$ for 1962, . . . , $i = 11$ for 1971).
A_i: dummy for age i ($i = 2, 3, . . . , 6$).

(4) Make dummies

MI: $= 1$ if the make of the car is I; $= 0$ if it is not. (Abbreviated as a dummy for make I.)

$M1$	American Motors	$M8$	Imperial
$M2$	Buick	$M9$	Lincoln
$M3$	Cadillac	$M10$	Mercury
$M4$	Chevrolet	$M11$	Oldsmobile
$M5$	Chrysler	$M12$	Plymouth
$M6$	Dodge	$M13$	Pontiac
$M7$	Ford		

(5) Notations for regressions:

u: disturbance
R^2:   multiple correlation coefficient squared
SSR: sum of squared residuals
SEE: standard error of estimate

(6) Further specifications

(a) Unless stated otherwise, the regression is unweighted.
(b) In the weighted regression, the weight is $\sqrt{\text{sales}}$ of the sample model divided by the average of $\sqrt{\text{sales}}$ over all the sample models in the year.
(c) In the table of the regression results, the figures in parentheses under the estimates are t statistics of those estimates.
(d) *denotes: divide the estimated coefficients of H, W, and L by 100, 1000, and 10, respectively.

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Comments on "Automobile Prices Revisited: Extensions of the Hedonic Hypothesis"

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HEDONIC price indexes are coming of age, and automobiles constitute the foremost example in the application of this technique. Griliches, of course, pioneered this wave; now Ohta is also a major contributor. The empirical work done by Ohta and Griliches (O & G) is so excellent that it seems fitting here to consider only some general methodological issues—of which Ohta and Griliches are clearly aware, but which they choose not to explore. I shall concentrate on two problems: that of unobserved characteristics, and that of discontinuities of characteristics. I shall then indicate the relevance of these problems to price indexes in general.

UNOBSERVED QUALITY CHANGES

The hedonic method of measuring a price index of a good subject to "model changes" appears on the surface almost as a miniature construction of a cost-of-living index. The good—an automobile in this particular application—is thought of as a set of attributes. In measuring the real price of the good, changes in quality have to be corrected for. In other words the levels of the attributes, equivalent to the quantity weights of a price index, have to be held constant. A major apparent difference in obtaining a price index for automobiles is that prices have to be inferred instead of directly observed. The main effort of the Ohta-Griliches paper is in determining the quantity base and in estimating the prices of the attributes.

There is another, perhaps more fundamental, difference: the process of obtaining a cost-of-living index essentially attempts a total enumeration of commodities, so that the consumer's budget is exhausted. In

practice, the list approaches a complete tally at least of the market components. On the other hand, the set of variables used to construct hedonic indexes not only falls short of totality but does not even constitute enumeration. For automobiles, most of the available hedonic indexes cover such attributes as length, weight, and power. In the current study, Ohta and Griliches try also "performance" variables such as "handling" and "ride." No matter how many attributes are added to either list, neither could ever constitute an exhaustive enumeration.[1]

Whether it would be worthwhile to redefine attributes so as to make enumeration possible, and then to try to obtain such an enumeration, I do not know. However, as long as full enumeration is not attempted in practice, the hedonic index varies from the conventional one. What are the implications of that lack of correspondence?

The difficulty in obtaining a correct measure of the price of automobiles is due to change in "quality." Except that relative levels of the attributes vary substantially over time, the problem of quality change would be immaterial and there would be no point in using data on automobiles made in different years in estimating the (shadow) prices of the attributes.

The first question that comes to.mind is: What forces induce the changes in quality? In the presence of stable demand functions, one source of variability is that changes in income lead to shifts in demand. The income-effected changes in the levels of each of the attributes and in their prices, then, would trace the attributes' supply curves.[2] If neither income elasticities nor supply elasticities of the different attributes — measured and unmeasured — differ much from each other, the hedonic approach is likely to produce a close approximation to the desired result, since the levels of the unmeasured components would change in approximately the same proportions as those of the measured attributes.

Changes in supply conditions of attributes, however, are much more troublesome. There is no particular reason why these would all change in the same proportion or even be correlated. In fact, many of the relative variations in the regression coefficients of attributes through time, as obtained by Ohta and Griliches, may be interpreted as just such changes. Thus, to take the very first example at hand, the ratio of the

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[1] The above distinction between conventional and hedonic indexes points to another problem. For a conventional price index, the quantity base can be obtained by directly observing what commodities the consumer purchases and in what quantities. The set of attributes to be used in an hedonic index have to be guessed by the economist.

[2] Competitive conditions are implicitly assumed here.

coefficient of weight to that of horsepower, which in this context is a measure of their relative prices, fell from 19 in 1955–1957 to 7 in 1958–1959 and to 0.25 in 1960–1961 (see O & G, Table 2). In general, it is unlikely that a change in the price of steel will be accompanied by a similar change in the price of such other inputs as upholstery materials, rubber, or labor. More important, there is no reason why the supply conditions of attributes the investigator chooses and is able to observe will change in the same proportion as those of the unobserved ones. If the change in the regression coefficients of weight relative to horsepower is an indication of the potential changes in supply conditions of observed relative to unobserved attributes, the consequence of leaving out some of the attributes may be rather serious.[3]

To simplify the analysis of the relation between observed and unobserved attributes, let us now assume that the entire set of attributes of a commodity such as an automobile can be collapsed into just two — the (composite) attribute accounted for and the (composite) one left out. Suppose that the marginal cost of producing the observed attribute has increased, while that of the unobserved attribute has remained unchanged. The supply curve of the observed attribute shifts along its demand curve; the price of the observed attribute will increase and its equilibrium quantity decline. As a result of the higher price, the demand for substitutes will increase and that for complements will decline. Without a priori knowledge of whether the observed and unobserved attributes are substitutes or complements, one cannot say what will happen to the quantity of the unobserved attribute.[4]

The question we are concerned with, however, is more specific. How, and in what direction, will the quantity of the unobserved attribute change *per unit* of the observed one? Under rather (but not quite) general conditions, the law of demand dictates that the higher price of the observed attribute will cause an upward shift in the *relative* quantity of the unobserved attribute.[5]

When the relative level of the unobserved attribute is increased, the measured change in quality will be biased downward. Moreover, the increased demand for the unobserved attribute will be accompanied by

[3] It seems ironic that a charge of not exploring the consequences of a "left-out variable" is thus brought against a paper in which Griliches collaborates.

[4] Though, given that these attributes are sold as a single package, complementarity seems more plausible.

[5] Interactions with other commodities, as well as income distribution considerations, could conceivably reverse the conclusion. Fixed proportions in consumption could also change the result, but given the observed variability in the empirical studies, it seems safe to reject that notion.

increased expenditures on it and, thus, also by higher expenditure per unit of the measured attribute. If the supply of the unobserved attribute is perfectly elastic, the changes in quantity and in expenditures will be proportional.[6] This change in expenditures is induced by, and consequently is correlated with, the change in price of the observed attribute [7] and will lead to an upward bias in the estimate of its coefficient.[8]

If the supply of the unobserved attribute is not perfectly elastic the basic argument still holds, but the results become less useful. The expenditure on the unobserved attribute may increase more or less than proportionately to its quantity, depending on whether the two are substitutes or complements. If complementarity prevails, the absolute amount of the attribute is less and the move down the supply curve will lead to a lower unit price of the unobserved attribute. It is even possible, then, that the increase in the *relative* quantity of the unobserved attribute will be exactly matched by a decline in its price so that total expenses on it per unit of the observed attribute remain constant – or the fall in price may so dominate that expenditure on the unobserved attribute will actually decline per observed unit.

A combination of strong forces of complementarity on the demand side and of highly inelastic supply, then, makes it difficult to detect what quality change may result from an increase in the relative level of the unobserved attribute. Since, however, both these forces tend to lose impact as adjustments are made to the initial change, the effects on quality can be more readily ascertained for long-run relationships.

A similar analysis carried out for the case of changing supply conditions of the unobserved attribute yields even more unwieldy results; in a sense that is of no great relevance, because while we can test for the implications of changes in the observed component, we cannot even detect changes in the unobserved one directly, let alone test for their implications.

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[6] The unobserved attribute might be the retail services supplied by automobile dealers as compared with the observed "wholesale" commodity. The notion of perfectly elastic supply does not seem unreasonable in that case.

[7] Note that the correlation between the coefficients of horsepower and of weight (O & G, Table 2) is close to −1. Failure to account for one of them obviously could have resulted in seriously biased estimates.

[8] As an illustration, consider the removal of the automobile excise tax. The lowering of the tax constitutes a reduction in the wholesale cost but not in that of the attribute "retail services." Since the relative cost of retail services has increased, their quantity per wholesale unit should fall. It should not be surprising then to observe that the retail price of a car of given technical specifications had fallen by more than the tax.

DISCONTINUITY IN ATTRIBUTES

The regression coefficients of horsepower center around 0.1 (O & G, Table 2). In constructing the hedonic index such a coefficient is interpreted as a function of price. Given the semilogarithmic form employed, the price depends on the levels of the other variables and will also change with the level of horsepower itself. We will now proceed by assuming for simplicity that price is constant and is equal to $1 per horsepower.

If a market existed where consumers could purchase as much horsepower as they wanted at the going price, the use of that price to construct the index would pose no new problems. However, since no such market is at hand, the price of horsepower can be derived only by indirect methods. The normal justification for using prices in the construction of indexes is that since consumers adjust their behavior to the prices (or, more properly, to the price-ratio) underlying the index, these properly constitute a measure of *marginal* rates of substitution in consumption. That justification is invalid when marginal adjustments at the going price are not available.

The actual choice facing consumers is between, say, a 200- and a 250-horsepower engine at a price differential of $50. At a price of $1 per horsepower, one consumer might have chosen 190 units; a second, 220 units; and a third, 260. Each now has, however, to settle on one of the two actually available.[9] At a single point in time, the market offers a variety of all-or-nothing propositions, with no provision for continuous marginal adjustments.

Suppose now that a new model in introduced with engine sizes increased to 220 and 270 horsepower, the implicit price per horsepower remaining at $1. The hedonic index will then stay constant, but the true cost of living will not. The second consumer, whose demand at $P = \$1$ is 220, can now get exactly what he wants and is obviously better off.[10] The third consumer still cannot get his desired quantity; 250 horsepower was too small for him but the new 270 horsepower is too big, and the change leaves him about as well off as before. The first consumer is now worse off since the available engine sizes are farther from the size he prefers.[11] The hedonic index, then, gives a correct result only by accident, as in the case of the third consumer.

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[9] It may be possible to modify the engine to change its power, but the price of $1 per horsepower does not apply to such modifications.

[10] If the slope of his demand curve is -0.01, he is now better off by $2, to *him* the real cost of the engine fell by about 1 per cent.

[11] If the slope of his demand curve is also -0.01, he is now worse off by $5.

The new engine sizes are presumably introduced due to some change in market conditions; for instance, the new and larger engine sizes may be in response to an increase in average income. However, it is important to recognize that some individuals, particularly those on the low end of the scale whose incomes did not increase, are actually hurt even though the price index did not record any change.

In the previous illustration, it was assumed that exactly two engine sizes are offered. It is clear that if one of them is withdrawn, and the price of the other is held constant, some consumers will be worse off and none better off. If a single new intermediate-size engine replaces the other two and is still priced at $1 per horsepower, one may presume that the sum of the dollar losses of the losers will exceed the corresponding gain to those better off. If a third engine size is added, some consumers will be better off and none worse off. The hedonic approach, however, by failing to incorporate discreteness in the offering of attributes, rather implicitly adopts a model that assumes perfect divisibility. Thus, if over time the number of engine sizes is increasing, the hedonic method is biased upwards.[12]

The limited number of engine sizes offered seems to reflect economies of scale in their production. May there not also be economies of scale with respect to the size of the engine?[13] If there are, the regression coefficient which measures the *average* price per horsepower will differ from the marginal price, which would decline with engine size.[14] Construction of a meaningful hedonic index under such conditions might present insurmountable problems.

UNOBSERVED ATTRIBUTES, INDIVISIBILITIES, AND CONVENTIONAL PRICE INDEXES

Although the foregoing comments have been explicitly directed to the hedonic approach, they actually apply, though probably somewhat less acutely, to other price indexes. How is a commodity defined and measured for purposes of, say, the Consumer Price Index? Most likely, the units adopted to construct the index are the same as those actually

[12] While Ohta and Griliches do not explicitly give the number of engines available in the market, they make it clear that the number of automobile models has increased substantially in recent years.

[13] The semilogarithmic form employed by Ohta and Griliches implies *diseconomies*. They report that experimentation with the squares of the hedonic variables proved significant, but signs of coefficients are not provided.

[14] The diseconomies implicit in the form Ohta and Griliches are using means that average price is higher than price on the margin. Consumers presumably will use the latter in their calculus.

used in the market. It is costly to measure and to explicitly price all dimensions of a commodity. Consequently, the market is likely to select a limited number of attributes by which a commodity is measured while others remain implicit. A change in the price of the explicit attributes relative to the implicit ones will lead to substitution and produce results of the type just discussed with respect to the unobserved hedonic attributes.

For instance, the Consumer Price Index often controls the physical features of a commodity but not the conditions of purchase — whether the service in a store is speedy, whether air conditioning is provided, whether it is well stocked, and so on. We would predict that as the wholesale cost of a commodity rises while the supply conditions of retail services remain constant, the quantity of retail services per unit of the good will increase. This will result in an increase in the retail price as normally measured exceeding that in the wholesale price. The increase in the quantity of retail services is a quality improvement, but since it is not accounted for, the consumer price index becomes biased upwards.

Most commodities are subject to significant indivisibilities and most commodities command substantial quantity discounts. There are, for example, economies of scale to headaches: the per-tablet price of aspirin is about three times higher by the dozen than by the hundred, and the cheapest way to get exactly thirty-five tablets is by buying a bottle of fifty and throwing away fifteen. The simplification adopted for purposes of constructing the index — assuming a single price (Which one?) and continuity of quantity — seems rather costly, and it obscures a wide range of economic behavior.

The problematic nature of enumerating attributes and of divisibility as brought to the fore by the hedonic method may help economists in realizing that all market transactions are more complex than virtually any text in economics, elementary or advanced, may lead us to believe. It also may help us realize that equalizing on *all* economic margins is not a common market phenomenon.

The previous discussion points to difficulties associated with the hedonic as well as with conventional price indexes, without suggesting how the difficulties may be resolved. If our only purpose is to obtain more accurate price indexes, the criticism is indeed unconstructive.

However, if we are interested in understanding the economic process, I believe that the preceding comments can serve some useful ends. The problem of the unobserved attributes offers a tool for testing the law of demand. The explicit recognition of discontinuities points

to the need of constructing a testable model to indicate how choices are made with respect to the spacing and number of discrete offerings. These two issues, I feel, are ubiquitous and important and call for a major effort toward providing satisfactory explanations.

Reply to Yoram Barzel

MAKOTO OHTA AND ZVI GRILICHES

IT is not clear to us that the CPI and similar indexes are much better at "complete" enumeration. The hedonic indexes never aimed at "completeness," concentrating instead on a few, hopefully major, variable dimensions, letting the rest be impounded in the constant term. In any case, there is no cure against "left-out" characteristics without specifying more explicitly what has actually been left out. Otherwise, it is no different from a general allegation of "unmeasured quality change" against any kind of index.

Discontinuity and nonlinearity of the price schedule is a serious problem not treated adequately anywhere, as far as we know. To discuss it here will take us too far afield. We shall therefore only note, for whatever cold comfort this may bring us, that the same problem plagues also the CPI and all other similar indexes.