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M. K. Berkowitz & Associates Limited

Product characteristics that reduce energy use : the case of automobiles (final report)

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PRODUCT CHARACTERISTICS THAT REDUCE ENERGY USE: THE CASE OF AUTOMOBILES

FINAL REPORT

Prepared for

CONSUMER AND CORPORATE AFFAIRS CANADA

M. K. BERKOWITZ & ASSOC. LTD.

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EXECUTIVE SUMMARY

I. Introduction

The primary goal of this study is to identify the characteristics that influence the energy efficiency of automobiles and determine how the value of these characteristics to consumers has changed in response to changing gasoline prices. To achieve this objective, a general relationship between the price of an automobile and the amount of the characteristics that effect energy consumption within an automobile is developed. This relationship is known as an hedonic pricing model and the coefficients of the characteristics are referred to as hedonic, or implicit, prices. That is, the hedonic price of a characteristic is the implicit price paid for that characteristic when the good is purchased. Insofar as prices paid by consumers generally reflect the value of the good purchased, the hedonic prices of the characteristics similarly reflect their value to consumers.

The particular objectives of the study are to:

(a) Review and analyze the relevant literature;

(b) Formally develop the theoretical construct that relates product attributes to consumers' utility in order to determine amounts consumers are willing to pay for various product characteristics which in turn will indicate how much energy prices must rise in order to effect a change in consumption;

(c) Examine product characteristics that reduce energy use and relate these to the framework of the economic pricing model;

(d) Test results of the hedonic pricing model developed - applying the model to automobile purchases and potential energy savings;

(e) Discuss the impact of uncertain technological development on short-run energy savings; and

(f) Examine and indicate the applicability of the model to furnace purchases.

II. Review of the New Consumer Theory and Its Relationship to Hedonic Pricing

Closely related to the theory of household production is the Lancastrian (1966, 1971) view that a good is a bundle of characteristics and consumers purchase goods not for their own right, but for the underlying characteristics provided by the good. Whereas the problem addressed by Lancaster is for consumers to choose the goods which embody the particular set of characteristics that maximizes his utility for given product prices, the hedonic pricing model is concerned with measuring the prices of the individual characteristics implied by the price paid by consumers for the good. It is shown that the hedonic pricing model is merely an estimation of the Lancaster efficient frontier. The potential non-linearity of the efficient frontier, moreover, provides justification for estimating the hedonic pricing model using a semi-logarithmic form of the model.

III. Automobile Characteristics That Reduce Energy Use

Having developed the relationship between Lancaster's new consumer theory and hedonic pricing, an examination was undertaken to identify the relevant characteristics that effect the energy efficiency of automobiles. It was determined that for each of the years 1977 through 1980, in which

Canadian automobile efficiency data were available, vehicle weight and cubic inch displacement consistently explained over 80 percent of the variation in energy efficiencies across automobiles. Over the years examined, however, there appears to be a decline in the effect of weight on energy efficiency, likely due to the impact of technological improvements in producing lighter vehicles.

IV. Estimation of the Hedonic Pricing Model

Next, the hedonic pricing model was estimated using the characteristics that reduce energy consumption as well as other characteristics that were expected to explain the variation in automobile prices across models. Among the more interesting results, it was observed that the interior volume of vehicles was only considered important (i.e., had a statistically significant hedonic price) by consumers in 1980, following major downsizings by the industry. Furthermore, when sales were weighted by market share and the model was estimated on standard North American vehicles alone, weight and number of cylinders explained about 90 percent of the variation in automobile prices across models in each test year. The relationship appears linear rather than non-linear, as well. Moreover, irrespective of the particular explanatory variables included, the weighted model always performed better than the unweighted model with the same independent variables.

When the original sample was supplemented by non-standard vehicles, the bias introduced by our assumption that used car sales reflect original sales of the new models was more serious due to the variation in durability across vehicles in the appended sample. Even though the results indicated a significant positive amount that consumers are willing to pay for purchasing a non-standard car, perhaps due to a difference in quality, the bias introduced with this sample resulted in consistently lower R^2's.

When the hedonic prices of weight and number of cylinders, for one-year old vehicles, were compared to real domestic gasoline and oil prices, the relationship was as expected. An increase in energy prices decreased both the value attached to weight and additional cylinders by consumers. To confirm the relationship between energy prices and energy consuming automobile characteristics, we also examined the Black Book values for air conditioning, automatic transmission, and additional cylinders for two periods - December 1978-79 and December 1979-80. During the first period, there was a decrease in real gasoline prices while the second period was one in which real gasoline prices showed a dramatic increase. Generally, the change in values suggested by the Black Book for these three characteristics were consistent with the change in energy prices.

V. The Supply and Demand of Durability in an Uncertain Technological Environment

Next, we examined both the demand and supply of durability in an uncertain technological environment. The motivation for this discussion is that for many energy intensive capital goods, like automobiles, furnaces, etc., the potential for future technological change may imply that such goods be produced at a lower durability so that consumers have the flexibility to purchase the more energy efficient technology as it comes on stream. The results of the analysis suggest that the greater is the market power of firms in the industry, the lower is the level of durability supplied which may be in the consumers' interests. At the same time, however, product durability is a potential barrier to entry so that firms may have an incentive to produce goods of a longer life in order to discourage entry into the industry. In the automobile industry, other barriers aside from product durability are likely responsible for the existing structure of the industry so that the offered durability of automobiles is most influenced by the monopoly power of the industry and is, therefore, less than would be offered by firms in a competitive industry.

VI. Implications and Other Applications

A number of policy implications arise from this study. First, the claim has often been voiced that North American automobile manufacturers build a product of too low a durability, or they build obsolescence into their products. The analysis conducted in this study suggests that these firms do have an incentive to produce automobiles of a lower level of durability than would firms in a competitive industry. At the same time, however, offering products of low durability may be in the interests of consumers if industry members are seriously engaged in research and development directed toward improved vehicle energy efficiency. The ability of firms in this industry to withhold adoption and utilization of such an invention for reasons relating to self-profitability undermine the positive effects associated with the lower durability product offered by industry members. To encourage the future technological advances required for any benefit to be realized from consumers purchasing automobiles today of lower durability, it is important to have research and development conducted independently of the industry - perhaps even supported or directly undertaken by government.

Another implication of this study relates to the tradeoff observed between vehicle weight and energy efficiency. Automobiles have become lighter since 1977 as witnessed by the average curb weight adjusted for market share of the sample used in this study - 3292 pounds. On the other hand, in 1980, the adjusted average weight of the sample was 2920 pounds, a decrease of 11 percent. Associated with this reduction in weight has been an increase in energy efficiency along with a concomitant dollar savings. However, also associated with the heaviervehicles are additional costs. That is, lighter weight automobiles incur greater damages, personal and property, which may increase insurance rates disproportionately for these cars. This extra cost burden, when deducted from the value of the energy savings, may significantly effect the demand for these vehicles.

While estimation of the energy savings associated with the change in automobile characteristics induced by higher gasoline prices was not possible due to the lack of sufficient time-series data, the required data appears to be available for home furnaces. Hence, the estimation procedure can likely be carried to its final step for furnaces and the aggregate energy reduction attributed to higher energy prices estimated.

CHAPTER ONE: INTRODUCTION

The theory of production within a firm postulates that the firm reacts to changes in factor prices, in the short run, by substituting the relatively abundant input with the lower price for the relatively more scarce and more expensive input. The ability of the firm to make these short run adjustments in response to changes in factor prices is related to the particular production technology employed by the firm. Only in the long run, as capital is replaced, can a new technology incorporating a more efficient (not necessarily the most efficient due to the dynamic nature of the problem) utilization of factor inputs be adopted.

Analogous to the firm's production process is the theory of household production in which Muth (1966) stated the central hypothesis that commodities purchased in the market are inputs into the production of goods within the household. The goods produced, in turn, are arguments of a conventional utility function of the household. For a given production technology, the household's ability to substitute between market commodities in response to changes in prices is limited. In the long run, however, the technology can change as a result of changes in tastes and the ability to substitute between commodities is enhanced.

Closely related to the theory of household production is the Lancastrian (1966, 1971) view that a good is a bundle of characteristics and consumers purchase goods not for their own right, but for the underlying characteristics provided by the good. The relationship between product characteristics and consumer attitudes and behaviour has received considerable attention in the literature. See, for example, Berkowitz and Haines (1981, 1982), Ladd and Zober (1977), and Bass and Talarzyk (1973) among others.

The problem addressed by Lancaster is for the consumer to choose the goods which embody the particular set of characteristics that maximizes the consumers' utility for given product prices. As particular characteristics become more or less desired by consumers, this is reflected by a change in the value of these characteristics or simply, as a change in the price the consumer is willing to pay for the characteristics.

This study adopts the Lancaster view of goods and concentrates on a particular good group - automobiles. The primary purpose of the investigation is to identify the characteristics that influence the energy efficiency of automobiles and determine how the value of the characteristics to consumers has changed in response to changing gasoline prices over time. The results derived in this study indicate a strong impact of energy prices on consumers' decisions to purchase more (or less) energy efficient automobiles and, hence, gasoline through the composition of characteristics embodied in the automobiles purchased.

The particular objectives of the study are to:

(a) Review and analyze the relevant literature;

(b) Formally develop the theoretical construct that relates product attributes to consumers' utility in order to determine amounts consumers are willing to pay for various product characteristics which in turn will indicate how much energy prices must rise in order to effect a change in consumption;

(c) Examine product characteristics that reduce energy use and relate these to the framework of the economic pricing model;

(d) Test results of the hedonic pricing model developed - applying the model to automobile purchases and potential energy savings;

(e) Discuss the impact of uncertain technological development on short-run energy savings;

(f) Examine and indicate the applicability of the model to furnace purchases.

The study is organized as follows. Chapter 2 reviews Lancaster's new consumer theory and its relationship to hedonic pricing. Chapter 3 presents the development of the hedonic pricing model. Chapter 4 examines the automobile characteristics that reduce energy use. Chapter 5 presents the results of alternative estimations of the hedonic pricing model and the relationship betweenthe hedonic prices of energy related automobile characteristics and energy prices.

Chapter 6 examines the related problem of consumer and producer choices with respect to the durability of an energy intensive capital good when future technological change is unknown. In particular, because the development of new technologies is uncertain, yet promise greater energy savings than can be achieved with redesigning the characteristics embodied in existing technologies, any incentive which encourages adoption of durable goods of the latter variety may postpone the development of new technologies by firms. Moreover, due to the durable nature of these goods, consumers who purchase products which incorporate the present technology will only purchase a newly developed, more energy efficient product, when the product currently being used depreciates.

Chapter 7 serves to summarize the preceding results, to discuss policy implications of the study, and to evaluate the applicability of the methodology used in this study for a similar examination of residential furnaces.

CHAPTER TWO:

A REVIEW OF THE NEW CONSUMER THEORY AND ITS RELATIONSHIP TO HEDONIC PRICING

I. Introduction

Traditional theory of consumer demand is based upon the assumption that consumers derive utility from the consumption of goods per se (i.e. apples, automobiles, radios, etc.). As with most theories, the passage of time has made apparent several weaknesses with this traditional approach to consumer behavior; for example, its inability to adequately predict the consequences of the arrival of a new good, or a change in quality of an existing good, or to explain why some goods are substitutes and others complements.

In spite of these weaknesses the traditional theory continued to be the one that was most widely accepted. At different times, however, a competing concept of goods has appeared in the literature, one in which objects are not simply considered goods, but instead as bundles of characteristics.[1] It was not until Lancaster (1966), however, that an attempt was made to integrate this concept of goods into the core of consumer theory.[2] Lancaster's theory is based upon the postulate that consumers derive utility from the intrinsic physical characteristics of goods.[3] This theory has come to be known as the "new theory" of consumer behavior and has served to somewhat bridge the gap between academic economic theory and practical application in the areas of multi-attribute attitude scaling in marketing and hedonic pricing in econometrics.

II. Lancaster Model

Lancaster's (1966, 1971) basic departure from the traditional theory of consumer behavior lies in the fact that goods themselves are not the direct objects of utility. Instead, it is the properties, or characteristics, of the goods from which utility is derived (i.e. goods are viewed as means rather than intrinsic ends). Therefore, the consumer's utility function is an ordinal preference function of characteristics rather than goods. Moreover, it is assumed that all characteristics have non-negative marginal utilities, i.e. more of a characteristic will always increase the individual's level of satisfaction or at the least, leave it unchanged.

Lancaster writes the individual's utility function as

$$U = U(Z_1, Z_2, \ldots, Z_J) \tag{2-1}$$

where Z_j is the amount of characteristic j obtained by the consumer.

A linear consumption technology (B) is assumed to relate the vector of characteristic totals to the quantities of commodities consumed (q's). That is,

$$Z_j = \sum_i B_{js} q_i \qquad \text{for all } j=1,J \text{ characteristics} \tag{2-2}$$

Lancaster assumes that the consumer chooses quantities of the continuously variable commodities so as to maximize utility subject to the consumption technology and the budget constraint. This is written:

$$\text{(2-3)} \qquad \text{Max } U = U(Z_1, Z_2, \ldots, Z_J)$$

$$\text{Subject to: } Z_1 = B_{11}q_1 + B_{12}q_2 + \ldots + B_{1N}q_N$$

$$\vdots$$

$$Z_J = B_{J1}q_1 + B_{J2}q_2 + \ldots + B_{JN}q_N$$

$$P_1q_1 + P_2q_2 + \ldots + P_Nq_N \leq Y$$

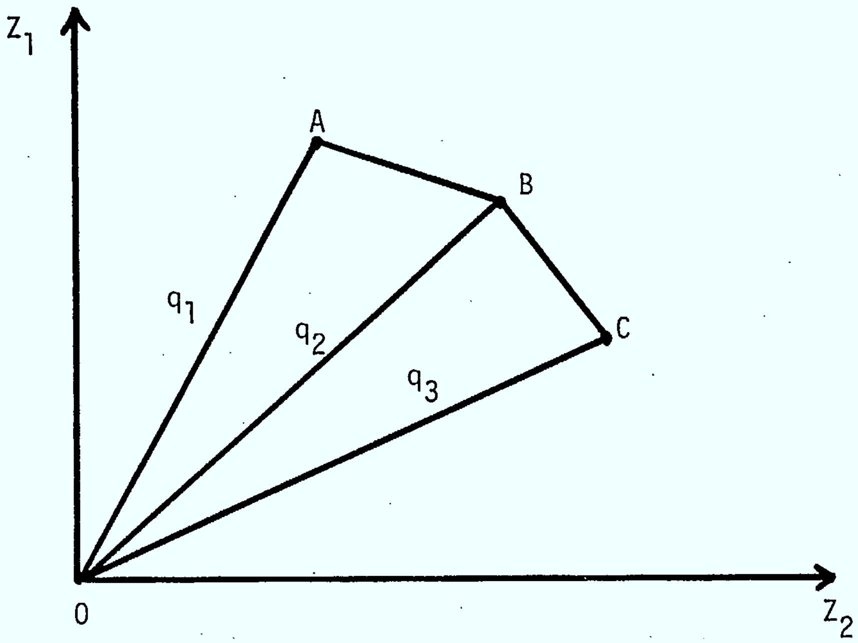
$$Z_j, q_n \geq 0$$

where P_n is the price per unit of the n-th good and Y is the consumer's income.

This non-linear program has a solution for the optimal bundle of characteristics (given that the number of goods is greater than or equal to the number of characteristics), which can be denoted by $Z^*(\equiv Z_1^*, Z_2^*, \ldots, Z_J^*)$. Graphically, the problem can be illustrated by mapping the budget constraint upon the characteristics space in order to determine the feasible set. For simplicity, let us assume that there are two relevant objectively measurable characteristics, Z_1 and Z_2 and three goods, q_1, q_2, and q_3 , which possess the two characteristics in different proportions and that the representative consumer has some given level of income Y . The feasible set of characteristics can be graphically represented as shown in Figure 2-1.

The rays OA, OB and OC represent the amounts of each characteristic associated with the purchase of q_1, q_2 and q_3 respectively, with the slopes of the rays indicating the ratio of characteristic Z_1 to Z_2 found in each good. The points A, B, and C indicate the

Figure 2-1



maximum amount of characteristics that can be obtained by spending all the income on the three goods, q_1, q_2 and q_3 individually. Therefore, the feasible set is given by the convex region OABC . If we superimpose the indifference curves on the graph, the optimal point is found where the highest indifference curve is just tangent to the convex set. At this point, the consumer's marginal rate of substitution is equal to the relative prices of the two characteristics, which is the value of the implicit price of Z_1 to the implicit price of Z_2 .

It should be noted that if the indifference curves are of the traditional kind (i.e. smooth, continuous and convex to the origin), the only possible area of tangency is the convex section ABC which is known as the efficiency frontier. The shape of the frontier is, moreover, the same for all consumers although its position relative to the origin may shift in a parallel fashion depending on the individual's level of income.

In general, once the optimal characteristics vector Z^* is determined, the optimal goods vector can be found by solving the following linear program written for notational convenience in matrix form:

$$\text{(2-4)} \qquad \text{Min } PQ \quad \text{subject to } BQ \geq Z^* \quad Q \geq 0$$

In summary, the Lancastrian theory formulates consumer choice as consisting of two parts: a) an efficiency choice, i.e. determining the efficiency frontier and the associated efficient goods collections, and b) a private choice, i.e., determining which point on the characteristics frontier is preferred. Once the optimum point in the characteristics space is found, this characteristics vector will correspond to a single goods vector only in situations where the number of goods is greater than or equal to the number of relevant characteristics. This is, however, likely to be the case in a complex economy where there are a large number of different varieties to choose from in any particular group of goods.

III. The Lancaster Theory and Hedonic Pricing

Suppose now that we examine the relationship between the Lancastrian view of consumer choice and hedonic pricing. First, however, let us define exactly what we mean by the latter term. Hedonic pricing is a technique in which the per unit price of a good is assumed to be a function of the absolute amounts of the relevant characteristics embodied in it (i.e., $P_n = f(Z_{1n}, Z_{2n}, \ldots, Z_{Jn})$ where Z_{jN} is the absolute amount of characteristic j per unit of good n). The empirical application of this concept basically involves regressing the price of the good on the amounts of the relevant characteristics contained in it. The characteristics, in theory, must be cardinally measurable and completely divisible, but often in practice, discrete characteristics are included. Depending on the form of the hedonic function, the coefficients of the characteristics are either the implicit prices of the characteristics themselves, or can be used to determine the implicit prices.

To understand the relationship between the hedonic price function and the Lancaster theory, let us rewrite the linear programming problem outlined in (2-4) in terms of the dual problem, i.e.

$$\text{(2-5)} \qquad \text{Max } \rho Z^* \quad \text{subject to} \quad \rho B \leq P$$

where ρ are the shadow (or hedonic) prices of the characteristics. Though written in matrix form, the above problem has N constraints, one for each good within the consumer's choice set. For those constraints that are binding, i.e. satisfied as an equality in the optimal solution,

$$\text{(2-6)} \qquad \rho B^s = P^s$$

where P^S is the solution sub-vector of P and B^S is the solution sub-matrix of B . This result is a linear specification of the hedonic price function. Unfortunately, however, estimation of the hedonic price function has often been accomplished using a non-linear specification, i.e. double logarithmic or semi-logarithmic. How can we rationalize the non-linear specification for estimation purposes with the linear relationship suggested by the theory in (2-6)? Fortunately, this problem has been addressed by Lucas (1975).

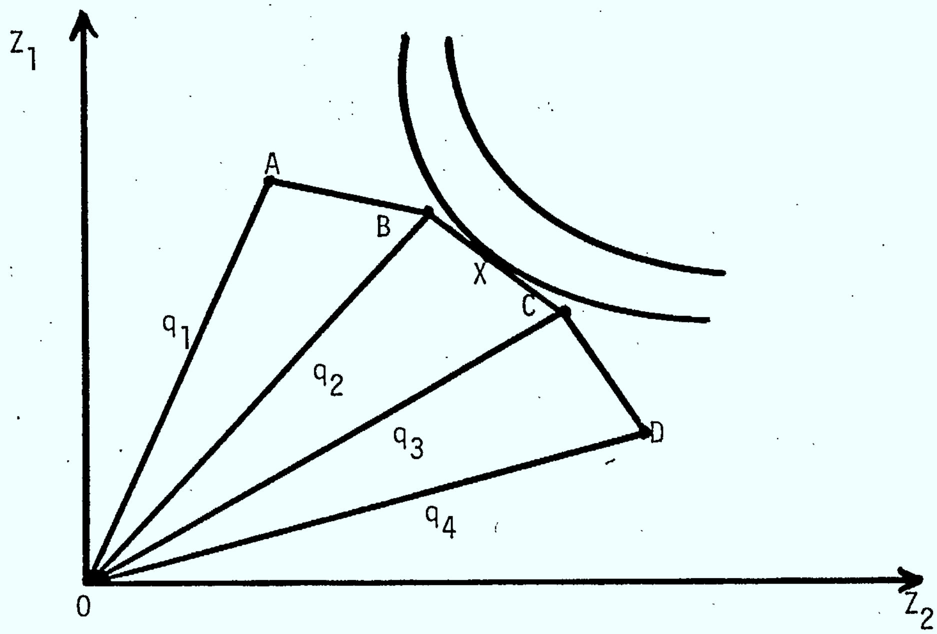
The argument made by Lucas runs as follows. Suppose we examine the case of a single, representative consumer as assumed by Lancaster. Estimates of hedonic price functions are typically obtained by treating each commodity (brand or model) as an observation. Thus, if one is to estimate the hedonic function by multiple regression analysis, to have a positive number of degrees of freedom in order to give confidence to the estimates, it is necessary that the true relation should hold for a greater number of commodities than characteristics.

In the non-degenerate program (i.e. where positive levels of at least some goods are chosen in the optimal solution) it is well known that the consumer will choose to consume no more commodities than there are characteristics. That is, if there are three relevant characteristics, no more than three commodities from the choice set will be consumed. It follows that (2-6) holds for at most J commodities and cannot, therefore, be the hedonic price function estimated by multiple regression.

This, according to Lucas, is not the end of the story, however, for the representative consumer. Suppose we examine in Figure 2-2 the case of two characteristics (Z_1 and Z_2) and four goods ($q_1,\ldots,q_4$)

within the Lancastrian characteristics space.

Figure 2-2



The locus ABCD is the efficient frontier. As drawn, the representative consumer will choose that combination of goods 2 and 3 which provides the characteristics package represented by point X . The equalities in (2-6) then hold for commodities 2 and 3, which raises the interesting issue of what happens to the other goods, i.e. 1 and 4.

Since there is zero demand for commodities 1 and 4 at the going prices of these goods, they are clearly in excess supply if they appear at all. If markets are stable, the prices of these goods fall. Unless the supply of these goods falls to zero before they enter the solution set, prices will continue to adjust until points A through D lie on the same plane. While the number of commodities with positive consumption levels is indeterminate (dependent upon the adjustment of prices), the consumer may in this case choose to consume <u>more</u> than J commodities.

Thus, in the situation described by the representative consumer, when prices have adjusted, the number of binding constraints in (2-6) may be greater than the number of characteristics. In general, then, it is true that (2-6) can be estimated by multiple regression analysis, but is it the equation <u>actually</u> estimated by most researchers? The situation described by (2-6) implies a strictly linear specification of the hedonic price function, yet, as Griliches (1971) notes, "Most investigators settle after some experimentation for a semi-logarithmic relationship between prices and characteristics..." Can we reconcile empirical applications with the theory?

Consider again the consumption possibility frontier in Figure 2 represented by ABCD. A linear hedonic price function holds for the same number of goods as characteristics. Such equations hold, however, with a different ρ vector for each facet, i.e. AB, BC, or CD. Therefore, a piecewise linear function relates commodity prices to characteristics for all commodities on the frontier. Moreover, Lucas argues that this function cannot be estimated by taking break-points in the characteristic variables at values corresponding to the vertices in the true equation and applying a piecewise linear estimator, since each segment of the piecewise linear equation would only involve the same number of commodities as there are characteristics. Hence, we are left with zero degrees of freedom. However, a non-linear function can, in general, be estimated to approximate the piecewise linear equation, and this is a plausible interpretation of the estimated non-linear hedonic price functions.

A non-linear hedonic price function capable of estimation by multiple regression analysis, and interpreted as representing variations in commodity prices and characteristics around the efficient frontier, requires that the Lancastrian consumer problem be non-degenerate. If some quantity of every good used to estimate the hedonic price function is observed to be consumed, then we know that the single representative consumer cannot be on the efficient frontier. Hence, the concept of the representative consumer must be abandoned.

Any number of consumers facing the same choice set of commodities with a common price vector, and constrained by the same consumption technology, has, as pointed out earlier, the same shaped consumption possibilities frontier in characteristics space. Consumers having different preferences, or different incomes and non-homothetic indifference curves, will, in general, be at equilibrium at different points on the same frontier. For example, in Figure 2-2, one consumer may be in equilibrium at a point on the AB facet, another on the BC facet, and yet another on the CD facet. In the absence of the representative consumer myth, observed positive amounts of every good used to estimate the hedonic price function correspond to these different equilibrium points and the estimated hedonic price function is no more than an estimation of the efficient frontier, which may very well be non-linear.

A closely related argument for the hedonic pricing function being an estimate of the efficient frontier was made by Rosen (1974). Rosen begins, unlike Lancaster and Lucas, with the assumption that the various goods sold in a market are indivisible and a consumer buys only one model or brand per period, say a year. Assuming further that brands are availabel for a continuous range of characteristics, Rosen is able to eliminate the problem of transformation of the desired characteristics into the optimal consumption of goods, i.e. the second stage of the Lancastrian optimization procedure. The optimization proceeds instead directly in terms of prices and quantities of characteristics.

Assuming one good group (e.g. automobiles) yielding characteristics $Z_1, Z_2, \ldots, Z_J$ and letting Y represent all other goods consumed, Rosen's model is simply:

$$\text{(2-7)} \qquad \text{Max } U(Z_1, Z_2, \ldots, Z_J)$$

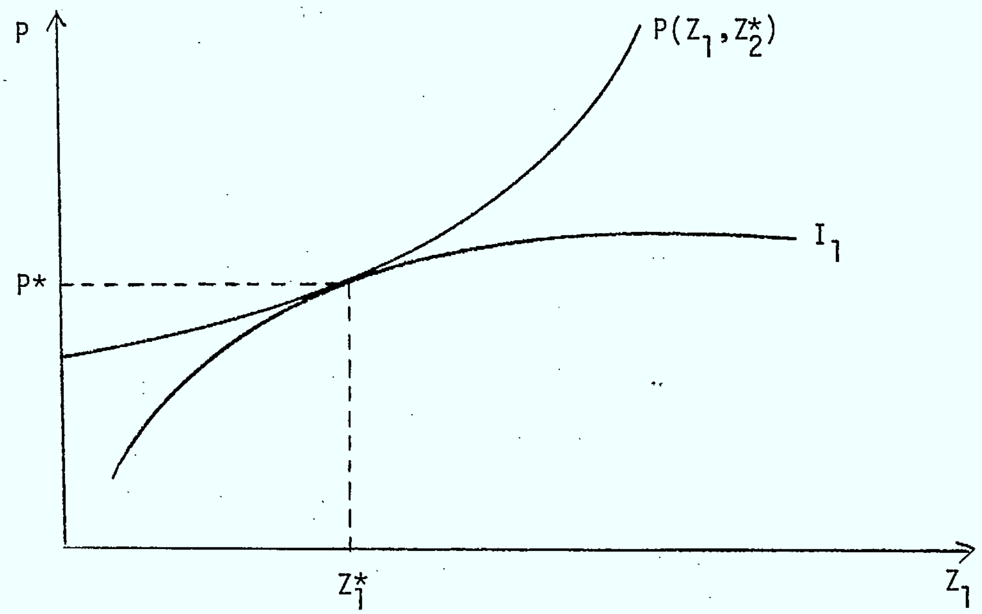
$$\text{subject to } P(Z_1, Z_2, \ldots, Z_J) + Y = K$$

where the price of the composite good Y is normalized to one dollar, K is income, and $P(Z_1, Z_2, \ldots, Z_J)$ represents the price of the one good yielding characteristics $Z_1, Z_2, \ldots, Z_J$ which is actually purchased. Unlike the traditional model where marginal utilities are proportional to prices, the problem outlined in (2-7) has as its solution that the marginal utilities of characteristics are proportional to their marginal prices, $\frac{\partial P}{\partial Z_i}$.

As in the Lancaster model, the Rosen model implies an efficiency frontier defining the combinations of characteristics available at any given expenditure, and that the consumer will choose the combination so as to maximize his utility. In addition, the Rosen model emphasizes the tradeoff between total consumption of characteristics and their cost, which represents the value of other goods which must be foregone so the individual may purchase characteristics.

To illustrate the Rosen model, let us look to Figure 2-3 where we assume two characteristics, Z_1 and Z_2 , and an indifference surface, I_1 , which shows the amount a consumer is willing to pay for a given set of characteristics at a given utility index. That is, I_1 defines the amounts the consumer is willing to pay for alternative amounts of Z_1 at a constant utility level U^* and given the value of $Z_2 = Z^*$. Moreover, the function $P(Z_1,Z_2^*)$ defines the brands which are available at the various combinations of price and Z_1 given $Z_2 = Z_2^*$. Given that Z_2^* is simultaneously the optimal level of Z_2 , utility is maximized when tangency is obtained between the consumer's indifference curves for price versus Z_1 and the function $P(Z_1,Z_2^*)$. In Figure 2-3, the consumer will choose the combination P^*, Z_1^*, Z_2^* .

Figure 2-3



In the Lancaster's model, owing to the divisibility assumption, the function P is linear, or piecewise linear, and the efficient frontier can be represented in terms of characteristics per dollar. In the Rosen model, however, P need not be linear because units of goods are not divisible. The empirical implication is that price must be represented as a separate dimension, and that characteristics of goods should be defined in terms of their absolute levels rather than characteristics per dollar. Given two characteristics, for example, the efficiency frontier would be three dimensional in price, Z_1, and Z_2.

It follows directly that the $P(Z_1,Z_2,\ldots,Z_J)$ function in Rosen's model is simply an hedonic price function which estimates the efficient frontier defining the various combinations of price and characteristics available to consumers. Moreover, to emphasize the point just made, P need not be linear because of the indivisibility of the good.

Finally, it should be noted that careful interpretation must be given to the coefficients of the estimated hedonic price function when cross-sectional data is used for estimation purposes. While individuals may assign different values (i.e. prices) to the characteristics and therefore lie at different points on the consumption possibility frontier, the estimated coefficients using multiple regression analysis represent the average values (or prices) of each characteristic over all consumers and goods within the sample.

IV. Applications of the Hedonic Pricing Model

Several different types of empirical studies have been done using hedonic price functions. The most common application is the determination of hedonic price indices for a particular group of goods. Briefly, the purpose of these studies is to correct consumer price indices for changes in the quality of the "constant" basket of commodities. The corrected price index is known as a quality adjusted price index and it, in theory, represents the pure price effect.

Without describing the exhaustive list of research, perhaps the most widely practiced use of hedonic price functions has been to investigate the determinants of house prices. In some cases, the regression model used has contained a mixed bag of explanatory variables; some physical characteristics, disposable income, neighbourhood factors and even a trend variable. Most of these regressions overlook the theoretical precepts and problems discussed earlier and therefore lack any theoretical foundation.

Other studies have closely followed the Lancastrian model, with only physical characteristics employed as explanatory variables. In two such studies, by Ball and Kirwan (1977) and Carvallio et. al. (1976), the results of their regressions were used to determine whether housing sub-markets exist within a larger urban area. To accomplish this, they tested the stability of the coefficients across the urban area. If the coefficients were found to be stable, they concluded that there would be only one urban housing market.

A study by King (1976) employed a two-stage Lancaster model. King grouped the physical characteristics together into housing services. The house prices were then regressed on the value of these housing services. Four services were used as explanatory variables and each proved to be statistically significant. King concluded that housing can be viewed as a bundle of relevant characteristics.

Murray (1978) supported King's findings that hedonic price functions using characteristics as explanatory variables were not as significant as those using housing services, because housing services were jointly produced by several characteristics.

Perhaps the second most popular use of hedonic price functions is their application in adjusting the price of automobiles for quality changes over time. Without exception, the particular form of the hedonic price function estimated in this literating is rather ad hoc, and chosen because it "fits" the data best. No theoretical foundation or explanation of what is being estimated, a la Lucas (1975) or Rosen (1974) can be found in any of these empirical exercises.

One of the earliest studies, by Griliches (1961), investigated the relationship between the list prices of U.S. automobiles to their various characteristics in 1937, 1950, and 1954-1960. The basic approach taken was to derive quality adjustment factors from cross-sectional data and use these factors to adjust a time series of automobile prices. Using a semi-logarithmic specification of the hedonic price function to determine the quality adjustment factors, Griliches concluded that a limited number of characteristics explain a very large fraction of the variance of car prices in any one of the years examined. Due, however, to the high collinearity between some of the characteristics, there appears to be instability in the estimated hedonic prices.

In a related study, Fisher, Griliches, and Kaysen (1962) used a model similar to Griliches' earlier one to estimate the costs to the consumer of changes in the specifications of private automobiles during the 1950s. In each year between 1950 and 1961, the R^2 (per cent of the price variation explained by the utilized characteristics) ranged from .857 to .951 using only four variables - horsepower, shipping weight, length, and a dummy for engine size. Because list prices of automobiles are used, the implicit characteristic prices estimated by the authors reflect a bias in terms of the costs to the consumer of changes in automobile specifications. As list prices diverge from transactions prices between years and between models, the results of this study must be interpreted with extreme care.

Triplett (1969) tried to duplicate the approach used by Griliches for the 1960-65 period. Unlike Griliches, he found that the hedonic measures indicated negligible quality improvement in automobiles and provide no substantiation for the belief in an upward quality bias in the CPI. Triplett pointed out that certain biases, however, in the hedonic indices themselves limit their validity as measures of quality change. To overcome the bias problem using regression analysis to estimate quality change, Triplett developed a quality index. Finally, he employed step-wise regression and found that only three variables (weight, a dummy for power steering, and a dummy for compact) could explain 90 per cent of the variance in list prices. It appears, however, that weight is a complex variable encompassing many aspects of quality. Moreover, the relationships between quality and weight was not stable over the estimation period (e.g. cars of equivalent quality have been made lighter with the use of aluminum and other light alloys), and this biases the results.

In a later study, Dhrymes (1971) estimated the hedonic price function for each of three U.S. automobile manufacturers. Because of the extreme collinearity in the explanatory variables, he employed principal component transformations to reduce the dimensionality of the data and to reduce the incidence of collinearity among the variables. Dhrymes found considerable instability in the coefficients of the characteristic variables and attributed this to the monopoly power of automobile manufacturers.

A related use of the hedonic price function appears in the work by Cowling and Cubbin (1971). In this study, the authors tried to explain the behavior of the oligopolistic U.K. car market over the late 1950s and through the 1960s. The assumption was that sales of an automobile are related to the quality adjusted price of the vehicle. Formally,

$$U_{it} = P_{it} - e[\alpha_{0t} + \alpha_{1t}V_{1it} + \alpha_{2t}V_{2it} + \cdots + \alpha_{nt}V_{nit}]$$

where U_{it} is the quality adjusted price of model i in year t; P_{it} is the list price of model i in year t; and V_{jit} is the amount of the j-th characteristic in model i in year t. For 1958, the estimated regression had an R^2 of .940, while for 1962, R^2 was .876. A significant improvement over previous studies was that Cowling and Cubbin weighted each observation by the market share captured by that model.

In order to determine the demand for automobile characteristics, Dewees (1974) tested both a linear and semi-logarthmic specification of the hedonic pricing model. For each year examined the R^2 was around .90. Moreover, in each equation, weight had the greatest degree of significance. Dewees found the implicit price of weight in 1968 was \$.509 per pound which is quite similar to the value obtained by Griliches (1961), assuming an automobile cost \$3,000 in the latter case. The weight coefficient derived by both Dewees and Griliches, however, were significantly below the values obtained by Triplett.

More recently, Toder (1978) developed an hedonic market share model for automobiles. The technique used selects the statistics describing a distribution of consumers' utility functions that reproduce the market shares of individual models actually observed. In doing so, an hedonic pricing model is estimated where instead of list prices, used one year old transactions prices are employed. The use of transactions prices represents an improvement over previous studies, yet the estimation procedure suffers since the characteristics are not weighted by sales of each model.

In summary, the estimated hedonic price functions adopted in these studies generally lack any theoretical foundation. For the most part, list prices have been used instead of transactions prices which contribute to a bias in the results. Moreover, the characteristics are usually unweighted by sales, suggesting that each model in the sample has an equal market share which is not the case. From an econometric standpoint, the explanatory variables are typically highly collinear so that the achieved high R^2's must be interpreted with extreme caution. Finally, in our review of the relevant literature, we have been able to identify 22 separate characteristics used in the hedonic studies of automobile prices. With the exception of weight, length, and horsepower, little concensus has been reached throughout the years. A summary of the characteristics employed by the various authors is presented in Table 2-1.

Table 2-1

SUMMARY OF CHARACTERISTICS USED IN PREVIOUS STUDIES OF AUTOMOBILE PRICES

Author(s)	Characteristics
Griliches (1961)	1, 2, 3, 12, 14, 15, 16, 17, 18
Fisher, Griliches, and Kaysen (1962)	1, 2, 3, 12, 14, 15, 16, 17, 18
Triplett (1969)	1, 2, 3, 12, 13(17)*, 14(15)*, 16, 18
Dhrymes (1971)	1, 2, 3, 4, 10, 13, 14, 18
Cowling and Cubbin (1971)	2, 3, 9, 11, 15, 19, 20
Dewees (1974)	1, 2, 3, 4, 5, 13, 21
Toder (1978)	1, 2, 3, 6, 7, 8, 14, 15, 17, 18, 22

where:
1: weight
2: length
3: horsepower
4: no. of cylcinders
5: engine displacement
6: brake area
7: turning circle
8: headroom
9: fuel consumption
10: production of relevant model
11: passenger area
12: dummy for engine size
13: dummy for number of doors
14: dummy for power steering
15: dummy for power brakes
16: dummy for compact
17: dummy for hardtop
18: dummy for automatic transmission
19: dummy for number of forward gears
20: dummy for luxury
21: dummy for standard accessories
22: dummy for station wagon

*Triplett included as single variables, dummies for 4-door hardtops, and power steering and power brakes.

CHATPER THREE: MODEL DEVELOPMENT

In order to develop the theoretical foundation for the model to be estimated in this study, we assume that consumer's utility is strongly separable in terms of good groups. Strong, or additive separability, is defined as the situation when the marginal rate of substitution between any two distinct groups is independent of the quantity of any commodity in any third group. We are thus able to concentrate on the consumer's choice problem between different models of automobiles given his available income for an ependiture on this good.

Suppose, initially, that we adhere to the concept of a representative consumer. Furthermore, suppose the utility he derives from purchasing and using an automobile is a function of the particular characteristics of the model chosen. Moreover, we can represent the vector of characteristics describing any model as Z so that utility, U, is a function of Z.[1]

The consumer tries to choose the model of automobile with the characteristics that maximize his utility. For automobiles, this appears at first glance to be a problem since the optimal characteristics might be achieved by purchasing one-third of a Cadillac and two-thirds of a Volkswagon. Recall from the discussion in the previous chapter that the problem of indivisibility of durable goods was addressed by Rosen (1974). Rosen recognized that it is both the supply and demand of these characteristics that determine the equilibrium prices observed. In effect, if consumers desire a package of characteristics that is a combination of a Cadillac and a Volkswagon, that product, with the desired characteristics, is produced and available in the market.

Thus, the problem facing consumers is the following:

$$\text{(3-1)} \qquad \text{Max } U(Z) \quad \text{subject to} \quad Z = Bq, \quad Pq \leq Y, \quad q, Z \geq 0$$

where B is a matrix transforming goods into characteristics; q is a vector of available models; P is a vector of automobile prices; and Y is the income available for an expenditure on automobiles.

Suppose the solution to the above problem for the representative consumer is the package of characteristics denoted by Z^* .

According to Lancaster (1971), the most efficient way of obtaining Z^* is to solve the following program:

$$\text{(3-2)} \qquad \text{Min } Pq \quad \text{subject to:} \quad Bq \geq Z^*, \quad q \geq 0$$

Alternatively, the dual of this problem can be written,

$$\text{(3-3)} \qquad \text{Max } \rho Z^* \quad \text{subject to:} \quad \rho B \leq P$$

Finally, for the model chosen, the constraint is binding and satisfied as an equality.

Because more than one model is observed to be purchased, the concept of the representative consumer must be discarded. Instead, suppose that individuals have different incomes and different preference functions for characteristics. Each of the M consumers will then choose the model that maximizes the value of his individual optimal characteristics package, Z_i^* . Hence, in aggregate there will be M binding constraints of the form:

$$\rho_{ij}B_{ij} = P_i \tag{3-4}$$

where a one-to-one correspondence between consumers and automobiles is assumed to exist. Because of differences in incomes and preferences, it is neither necessary nor likely that the values ascribed to characteristics by individual consumers (ρ's) be the same. Furthermore, this set of M equations represents the locus of points on the efficiency frontier that are tangent to the individual preference functions.

An average value of the j-th characteristic can thus be obtained by determining the average values of the ρ_{ij}'s over all N models and M consumers. To achieve this, let the number of consumers purchasing the i-th model be represented by n_i . Aggregating by model, the constraint set has the following form:

$$\begin{aligned} n_1[\rho_{11}B_{11} + \rho_{12}B_{12} + \ldots + \rho_{1J}B_{1J}] &= n_1P_1 \\ n_2[\rho_{21}B_{21} + \rho_{22}B_{22} + \ldots + \rho_{2J}B_{2J}] &= n_2P_2 \\ &\vdots \\ n_N[\rho_{N1}B_{N1} + \rho_{N2}B_{N2} + \ldots + \rho_{NJ}B_{NJ}] &= n_NP_N \end{aligned} \tag{3-5}$$

The average value of the j-th characteristic, ρ_j , is then the weighted average value, overall models, of that characteristic, i.e.

$$\rho_j = \frac{\sum_{i=1}^{N} n_i \rho_{ij}}{\sum_{i=1}^{N} n_i} = \sum_{i=1}^{N} \frac{n_i}{M} \rho_{ij} \qquad (3\text{-}6)$$

The use of cross-sectional regression analysis to estimate the hedonic prices of characteristics provides estimates of the ρ_j's . Aside from providing a theoretical construct for the empirical model to be estimated in this study, the foregoing analysis clearly demonstrates the need for weighting the characteristics by the sales volume of each model.

Hence, the model to be estimated can be expressed in linear form as:

$$P_i = \rho_0 + \rho_1 Z_{i1} + \rho_2 Z_{i2} + \ldots + \rho_J Z_{iJ} + \mu_i \,, \qquad (3\text{-}7)$$

or in semi-logarithmic form as:

$$\ln P_i = \rho_0 + \rho_1 Z_{i1} + \rho_2 Z_{i2} + \ldots + \rho_K Z_{iJ} + \eta_i \qquad (3\text{-}8)$$

The problem now is to determine the set of characteristics that effect the energy efficiency of automobiles so that we can examine the changes in the hedonic prices of these particular characteristics with respect to changes in gasoline prices over time.

CHAPTER FOUR:

EXAMINATION OF THE AUTOMOBILE CHARACTERISTICS THAT REDUCE ENERGY USE

In this chapter we shall examine the characteristics of automobiles that explain the variation in energy efficiencies across models for the years 1977-1980. Once the relevant characteristics are determined, they are input into the hedonic pricing model which will be estimated in the following chapter.

According to Dewees (1974), two vehicle parameters are important determinants of gas mileage - engine size and vehicle weight. In addition to their direct relevance, they are highly correlated with other variables. For example, at high speeds, gas mileage is affected by wind resistance which is a function of the frontal area of the automobile. This area is highly correlated with weight. Moreover, the rear axle ratio is an important fuel economy factor since it determines how fast the engine must turn over at a given vehicle speed. The axle ratio, however, is designed as a function of power and weight and thus in most U.S. manufactured automobiles, this factor has relatively little independent variation.

Dewees points out that the compression ratio is another variable related to fuel economy. As the compression ratio is raised in an engine with fixed displacement, the power obtained per gallon of fuel increases, along with maximum engine power. For the range of compression ratios currently in use, Kavanaugh et.al. (1958) approximated the relationship between gas mileage and the compression ratio as:

$$MPG = MPG^*(1 + .0625CR) \tag{4-1}$$

where MPG is the mileage per gallon adjusted for the compression ratio; MPG* is the mileage per gallon unadjusted for the compression ratio; and CR is the compression ratio.

Following Dewees, the relationship between the mileage variable unadjusted for the compression ratio and both the weight and cubic inch displacement (or horsepower due to high correlation between these variables) is multiplicative. Hence, the functional form can be represented by:

$$MPG^* = \frac{C}{WT^a \cdot CID^b} \tag{4-2}$$

where C is a constant; WT represents vehicle weight; CID represents cubic inch displacement; and a and b are positive parameters.

Substituting the value of MPG* from (4-1) into (4-2), we have

$$\frac{MPG}{1 + .0625CR} = \frac{C}{WT^a \cdot CID^b} \quad , \text{ or} \tag{4-3}$$

in logarithmic terms,

$$\ln MPG = \ln C + \ln(1 + .0625CR) - a\ln WT - b\ln CID \tag{4-4}$$

The equation to be estimated then has the following form:

$$\ln MPG = a_0 + a_1\ln CR + a_2\ln WT + a_3\ln CID \tag{4-5}$$

where the expectation from (4-4) is that the coefficient a_1 is positive while a_2 and a_3 are negative.

I. The Data

Data on the fuel economy of automobiles has been gathered by Transport Canada only since 1977. While such data has been collected for a longer period in the U.S., differences in automobile emission standards between the U.S. and Canada, which significantly influence fuel economy, preclude the use of the U.S. figures. Hence, we are restricted by the availability of data to consider only years 1977 through 1980 in this study.

A sample of standard North American built automobiles was selected in each year. Because market share data was only available by model of automobile sold in Canada for each year, the sample was limited to one vehicle per model even though models may vary by engine size, type of transmission, as well as other available options. To choose the most popular specification for each model we used the standard vehicle type listed in the Canadian Black Book for used car prices. If, for example, $200 was to be added to the given model prices if the model had automatic transmission, it was assumed that the most popular version of that model included standard transmission. On the other hand, if $200 was to be deducted from the given prices if the model had standard transmission, it was then assumed that the most popular specification was with automatic transmission. Appendix A to this chapter provides the specific models comprising the standard vehicles used in each year. Also included in the Appendix, for each year, are samples of non-standard (luxury, sport, etc.) models which are utilized in the study.

For each vehicle, data was collected on 16 characteristics, namely: (1) cubic inch displacement, (2) compression ratio, (3) horsepower, (4) type of transmission, (5) number of cylinders, (6) energy-efficiency in miles per gallon, (7) curb weight, (8) sales share, (9) width, (10) height, (11) length, (12) front head room, (13) front leg room, (14) front shoulder room, (15) rear seat room, and (16) rear shoulder room. As well, the used car price of each specific model was collected for the last week in December following each model year through 1980. That is, for 1977 model cars, used prices were collected as of the last week in December 1977-1980 while for 1980 models, data was gathered for the last week of December 1980 and included in the file. Since the Canadian Black Book lists four prices dependent upon the condition of the automobile (i.e. extra clean, clean, average, and rough), we used the average price as being representative of the particular make and model in any year.

The data was derived from six basic sources: (1) Transport Canada Fuel Economy Guide published by Transport Canada, (2) Automotive Service Data Book 1981 published by Maclean-Hunter Ltd., (3) Motor Vehicle Data Book published by Sanford Evans Services Ltd., (4) Automotive News, (5) Consumer Reports, and (6) Canadian Black Book published by William Ward publishing Ltd. Characteristics 1, 4, 5 and 6 were obtained from source 1, while characteristics 2, 3, 9, 10, and 11 were derived from source 2. Characteristic 7 was obtained from source 3. Characteristic 8 comes from source 4 and characteristics 12 through 16 were derived from source 5. Finally, used car prices were gathered from source 6.[1]

II. Regression Results

In order to estimate the model in (4-5), the compression ratio, weight, and displacement variables are utilized. Table 4-1 presents the estimated regression for each year. The coefficients are all of the expected sign though the compression ratio coefficient is not significant at the 95 per cent confidence level. Moreover, while not shown for years 1977 through 1979, approximately 90 per cent of the variation in energy efficiency across models is explained by the included variables, primarily weight.

In contrast, by 1980, less variation in energy efficiency can be explained by the included variables. Table 4-2 shows that mean energy efficiency increased during the four-year period with a significant reduction in the standard deviation. Also, the trend was toward a reduction in weight over the period, accompanied as well by a lower standard deviation. The explanation for these occurrences are twofold. First, during the period being considered, automobile manufacturers dropped their "guzzlers" which in turn reduced the variance in energy efficiency across models and improved the mean fuel economy. At the same time, this action likely reduced the mean weight and weight variation across models. Second, new energy conserving technologies were added over the period, which are not included as explanatory variables in the model. Hence, the R^2 is reduced though the mean energy efficiency is increased.

For completeness, the linear form of the model was also estimated and the results are presented in Table 4-3. As expected, the linear model does not perform as well as its non-linear counterpart.

Table 4-1

Relationship Between Energy Efficiency and

Characteristics of Automobiles

(t-statistics in parentheses)

Dependent Variable	Intercept	ln WT	ln CID[a]	ln CR	R^2
ln MPG (77)	10.636 (17.041)	-.922 (-8.742)	-.048 (-.847)	.139 (1.920)	.887
ln MPG (78)	7.586 (7.810)	-.531 (-4.069)	-.192 (-2.736)	.452 (1.397)	.869
ln MPG (79)	8.216 (14.075)	-.564 (-5.260)	-.144 (-2.516)	.163 (1.825)	.857
ln MPG (80)	6.387 (9.851)	-.310 (-2.544)	-.192 (-2.709)	.198 (1.955)	.824

a. Note that cubic inch displacement and horsepower are highly correlated. Either one could have been used as an explanatory variable. Dewees (1974), for example, reports his log-linear results using horsepower as an independent variable while the results of his linear model use cubic inch displacement as an explanator.

Table 4-2

Energy Efficiency and Curbweight

	Energy Efficiency (MPG)		Curbweight (LBS)	
	Mean	Std. Deviation	Mean	Std. Deviation
1977	27.57	6.65	3101.43	577.41
1978	27.95	6.42	3046.13	635.26
1979	28.37	6.09	2879.32	528.46
1980	29.00	4.24	2937.18	510.90

Table 4-3

Relationship Between Energy Efficiency and Characteristics of Automobiles

(t-statistics in parentheses)

Dependent Variable	Intercept	WT	CID	CR	R^2
MPG (77)	55.37 (18.476)	-.0103 (-7.952)	.0001 (.006)	.516 (2.725)	.840
MPG (78)	32.297 (2.906)	-.006 (-4.764)	-.017 (-1.548)	2.225 (1.698)	.817
MPG (79)	47.70 (19.467)	-.0070 (-6.209)	-.0125 (-1.385)	.4707 (2.175)	.829
MPG (80)	41.46 (16.096)	-.0030 (-2.620)	-.0346 (-3.220)	.3420 (1.520)	.717

For comparison, the results obtained by Dewees, based upon a sample of 106 vehicles, all of which satisfied U.S. emission standards and were tested for fuel economy in 1966 and 1967 are presented below:

$$\text{(4-6)} \qquad \ln MPG = 9.49 - \underset{(-5.045)}{.5321} \ln WT - \underset{(-6.644)}{.2991} \ln HP$$

with $R^2 = .89$, and

$$\text{(4-7)} \qquad MPG = 24.3 - \underset{(-6.047)}{.0026} WT - \underset{(-7.645)}{.0237} CID + \underset{(4.336)}{1.136} CR$$

with $R^2 = .87$.

A direct comparison between the equations in Table (4-1) with (4-6) is not possible due to the variation in samples. However, it is reasonable to conclude that the results we obtained are consistent with the earlier results of Dewees.

Looking closer at the results in Table 4-1, as we would expect, there appears to have been a fairly steady decline in the effect of weight on energy efficiency over the four year period due to the impact of technological improvements in producing lighter cars. For 1977 models, a one per cent increase in weight would reduce energy efficiency by about .90 per cent. For 1977 and 1978, a similar one per cent increase in weight would reduce energy efficiency by about .50 per cent. Finally, for 1980 models, a one per cent increase in weight would reduce energy efficiency by about .30 per cent.

The foregoing analysis argues strongly for the inclusion of weight in the hedonic pricing model. Moreover, the coefficient of the cubic inch displacement variable is significant and of the correct sign in each of the years 1978-80 for the logarithmic model and, hence, should also be examined within the hedonic framework. On the other hand, the compression ratio variable which was not significant at the 95 per cent level also proved insignificant during preliminary tests of the hedonic pricing model and was, therefore deleted from future analysis. Interestingly, Dewees (1974), Griliches (1967), and Triplett (1969) also excluded this variable, presumably for similar reasons.

Appendix

Standard Models Built in 1977

	Manufacturer	Model		Manufacturer	Model
1.	American Motors	Gremlin	20.	Ford	Granada
2.	" "	Hornet	21.	"	Maverick
3.	" "	Matador	22.	"	Pinto
4.	" "	Pacer	23.	Lincoln-Mercury	Bobcat
5.	Buick	Century	24.	" "	Comet
6.	"	Le Sabre	25.	" "	Monarch
7.	"	Regal	26.	Oldsmobile	Cutlass
8.	"	Skyhawk	27.	"	Omega
9.	"	Skylark	28.	Plymouth	Arrow
10.	Chevrolet	Chevette	29.	"	Fury
11.	"	Chevrolet	30.	"	Volare
12.	"	Malibu	31.	Pontiac	Acadian
13.	"	Monte Carlo	32.	"	Astre
14.	"	Nova	33.	"	LeMans
15.	"	Vega	34.	"	Pontiac
16.	Chrysler	Cordoba	35.	"	Sunbird
17.	Dodge	Aspen	36.	"	Ventura
18.	"	Charger			
19.	"	Monaco			

Standard Models Built in 1978

	Manufacturer	Model		Manufacturer	Model
1.	American Motors	Matador	21.	Ford	Fiesta
2.	" "	Pacer	22.	"	Ford
3.	Buick	Le Sabre	23.	"	Granada
4.	"	Regal	24.	"	LTD
5.	"	Skyhawk	25.	"	Pinto
6.	Chevrolet	Chevette	26.	Lincoln-Mercury	Bobcat
7.	"	Chevrolet	27.	" "	Monarch
8.	"	Malibu	28.	" "	Zephyr
9.	"	Monte Carlo	29.	Oldsmobile	Cutlass
10.	"	Monza	30.	"	Omega
11.	"	Nova	31.	Plymouth	Arrow
12.	Chrysler	Cordoba	32.	"	Fury
13.	"	Le Baron	33.	"	Horizon
14.	Dodge	Aspen	34.	"	Sapparo
15.	"	Challenger	35.	"	Volare
16.	"	Diplomat	36.	Pontiac	Acadian
17.	"	Magnum	37.	"	LeMans
18.	"	Monaco	38.	"	Phoenix
19.	"	Omni	39.	"	Sunbird
20.	Ford	Fairmont			

Standard Models Built in 1979

	Manufacturer	Model		Manufacturer	Model
1.	American Motors	Pacer	20.	Ford	Granada
2.	" "	Spirit	21.	"	Pinto
3.	Buick	Century	22.	Lincoln-Mercury	Bobcat
4.	"	Le Sabre	23.	" "	Capri
5.	"	Regal	24.	" "	Monarch
6.	"	Skyhawk	25.	" "	Zephyr
7.	Chevrolet	Chevette	26.	Oldsmobile	Cutlass
8.	"	Malibu	27.	"	Omega
9.	"	Monte Carlo	28.	Plymouth	Arrow
10.	"	Monza	29.	"	Horizon
11.	Chrysler	Cordoba	30.	"	Sapparo
12.	"	Le Baron	31.	"	Volare
13.	Dodge	Aspen	32.	Pontiac	Acadian
14.	"	Challenger	33.	"	LeMans
15.	"	Diplomat	34.	"	Phoenix
16.	"	Omni	35.	"	Pontiac
17.	Ford	Fairmont	36.	"	Sunbird
18.	"	Fiesta			
19.	"	Ford			

Standard Models Built in 1980

	Manufacturer	Model		Manufacturer	Model
1.	American Motors	Pacer	20.	Ford	Fairmont
2.	" "	Spirit	21.	"	Fiesta
3.	Buick	Century	22.	"	Ford
4.	"	Le Sabre	23.	"	Granada
5.	"	Regal	24.	"	Pinto
6.	"	Skyhawk	25.	Lincoln-Mercury	Bobcat
7.	Chevrolet	Chevette	26.	" "	Capri
8.	"	Chevrolet	27.	" "	Monarch
9.	"	Citation	28.	" "	Zephyr
10.	"	Malibu	29.	Oldsmobile	Cutlass
11.	"	Monte Carlo	30.	"	Omega
12.	"	Monza	31.	Plymouth	Grand Fury
13.	Chrysler	Cordoba	32.	"	Horizon
14.	"	Le Baron	33.	"	Volare
15.	Dodge	Aspen	34.	Pontiac	Acadian
16.	"	Diplomat	35.	"	LeMans
17.	"	Mirada	36.	"	Phoenix
18.	"	Omni	37.	"	Pontiac
19.	"	St. Regis	38.	"	Sunbird

Non-Standard Models Built in 1977

	Manufacturer	Model
1.	Audi	Fox
2.	BMW	320i
3.	Buick	Riviera
4.	Cadillac	Seville
5.	Chevrolet	Camaro
6.	Datsun	B210
7.	Ford	Mustang
8.	Honda	CVCC
9.	Lincoln-Mercury	Lincoln-Continental
10.	Mercedes	2400
11.	Oldsmobile	Toronado
12.	"	Delta 88
13.	Pontiac	Grand Prix
14.	Renault	5L
15.	Toyota	Corolla
16.	Volkswagon	Rabbit
17.	Volvo	242 DL

Non-Standard Models Built in 1978

	Manufacturer	Model
1.	American Motors	Concord
2.	Audi	Forx
3.	BMW	320i
4.	Buick	Electra
5.	"	Riviera
6.	Cadillac	Cadillac
7.	Chevrolet	Camaro
8.	Chrysler	Newport
9.	Datsun	B210
10.	Ford	Mustang
11.	"	Thunderbird
12.	Honda	Civic
13.	Lincoln-Mercury	Cougar
14.	Mercedes	230
15.	Oldsmobile	Delta 88
16.	"	Delta 98
17.	"	Toronado
18.	Pontiac	Grand Prix
19.	Toyota	Corolla
20.	Volkswagon	Rabbit
21.	Volvo	242 A

Non-Standard Models Built in 1979

	Manufacturer	Model
1.	American Motors	Concord
2.	Audi	Fox
3.	BMW	320i
4.	Buick	Electra
5.	Cadillac	Cadillac
6.	Chevrolet	Camaro
7.	Chrysler	Newport
8.	Datsun	B210
9.	Fiat	Brava
10.	Ford	Mustang
11.	"	Thunderbird
12.	Honda	Civic
13.	Lincoln-Mercury	Cougar
14.	" "	Marquis
15.	" "	Versailles
16.	Mazda	GLC
17.	Mercedes	240D
18.	Oldsmobile	Delta 88
19.	"	Delta 98
20.	"	Toronado
21.	Pontiac	Firebird
22.	Renault	12TL
23.	Toyota	Corolla
24.	Volkswagon	Rabbit
25.	Volvo	242 DL

Non-Standard Models Built in 1980

	Manufacturer	Model
1.	American Motors	Concord
2.	Audi	5000
3.	BMW	320i
4.	Buick	Electra
5.	Cadillac	Cadillac
6.	Chevrolet	Camaro
7.	Chrysler	Newport
8.	Datsun	B210
9.	Fiat	Brava
10.	Ford	Mustang
11.	"	Thunderbird
12.	Honda	Civic
13.	Lincoln-Mercury	Continental
14.	" "	Cougar
15.	" "	Marquis
16.	Mazda	GLC
17.	Mercedes	240D
18.	Oldsmobile	Delta 88
19.	"	Delta 98
20.	"	Tornado
21.	Pontiac	Grand Prix
22.	Renault	12 TL
23.	Toyota	Corolla
24.	Volkswagon	Rabbit
25.	Volvo	242DL

Chapter Five :

THE HEDONIC PRICING MODEL

I. Introduction

While most estimated hedonic price functions adopted in previous studies suffer from a lack of any supporting theoretical construct, the model to be estimated in this study has a theoretical basis which was developed in Chapter 3. For the most part, as well, automobile list prices have been used instead of transactions prices in estimating previous models. This contributes to a bias in the results. While new or transactions prices are not possible to obtain, used car transactions prices are available and have been used in this study to reduce the estimation bias. Yet another problem with many earlier studies is that the automobile prices and characteristics are typically unweighted, suggesting that each model in the sample has an equal market share which we know is not the case in the "real" world. In the following analysis we explicitly weight each model by the sales of the model in the particular year. It is expected that the inclusion of these considerations which have been generally omitted in previous studies will result in more reliable estimated implicit (or hedonic) prices of the characteristics associated with automobiles.

The results presented here suggest that when the hedonic prices of the weight and cylinder characteristics are compared to the historical trend in domestic gasoline prices, it appears that consumers are reacting correctly to the signals given in the marketplace.

II. The Model

Two variations of the hedonic pricing model are estimated: the linear form and the semi-log form. More specifically,

$$(5\text{-}1) \qquad P_{jtv} = a_0 + a_1 Z_{j1v} + a_2 Z_{j2v} + \ldots + a_n Z_{jnv} \quad \text{and}$$

$$(5\text{-}2) \qquad \ln P_{jtv} = b_0 + b_1 Z_{j1v} + b_2 Z_{j2v} + \ldots + b_n Z_{jnv}$$

where P_{jtv} is the price in period t of a model j automobile of vintage v and Z_{jiv} refers to the amount of characteristic i included in a model j automobile of vintage v. As an example, $P_{3,1978,1977}$ refers to the price in 1978 of a model 3 (e.g. Chevrolet Nova) car manufactured (sold) in 1977. Furthermore, $Z_{3,2,1977}$ refers to the amount of characteristic 2 (e.g. weight) in a model 3 car manufactured in 1977.

III. Data

The automobile price and characteristics data have been described in Chapter 4, Section I, and are not reproduced here.

IV. Estimates of the Models

Recall that in Chapter 4, an examination was undertaken of the automobile characteristics that reduce energy use. The results showed that over 80 percent of the variation in miles per gallon can be explained by the automobile's compression ratio, weight, and engine displacement. Because only the weight coefficient was consistently significant over the four year period, the starting point for estimation of the hedonic pricing model was to use the weight variable in combination with variables representing the number of cylinders, compression ratio, displacement, and interior volume so as to explain the variation in automobile prices across standard models in any year.

The reasons for including dummy variables for the number of cylinders is that this characteristic has been a common explanator within many previous studies.[1] Moreover, it is expected ex ante that the hedonic price associated with the number of cylinders is quite sensitive to gasoline prices.

The volume variable was examined as an explanator because it was believed that the value of this characteristic has changed over time with gasoline prices and the substantial downsizing of automobiles in recent years. That is, it was expected that interior volume was of little relevance to consumers when automobiles were large and a high correlation existed between size as measured by weight and interior vehicle volume. Once gasoline prices rose and were expected to rise further, however, weight was reduced by automobile manufacturers, but interior volume did not necessarily decrease proportionately, reflecting consumers' preferences for this characteristic. To estimate interior volume, the product of the width, length and height of the interior cab was used.[2] It should be recognized that this estimate is somewhat biased since the cab is measured as a box so that the more aerodynamically built is the car, the greater is the bias.

Though the coefficients associated with the models which included compression ratio and engine displacement variables were estimated, these variables were consistently non-significant and so are not presented here. Looking first to the samples of standard automobiles described in the Appendix to Chapter 4, Table 5-1 presents estimates of the linear model coefficients of vehicle curb-weight (CURBWT) and the two dummy cylinder variables, D1 and D2. For purposes of interpretation, it should be kept in mind that D1 = 1 if a vehicle has 4 cylinders and zero otherwise D2 = 1 if vehicle has 6 cylinders and zero otherwise. These results are based upon the implicit assumption that each model had an equal share of total automobile sales in the particular year, i.e., the variables are unweighted by sales share.

Looking at the equation in which the prices of one-year old 1977 models serve as the dependent variable, the results show that extra weight is valued at approximately $.603 per pound. The value of weight, moreover, decreases to approximately $.481 per pound for one-year old 1978 models and stays about at that level for one year old 1979 and 1980 models.

The cylinder dummy variables also have an interesting interpretation. For one-year old 1977 models, a 4-cylinder car sold at a discount of $860.28 relative to an 8-cylinder model while a 6-cylinder model sold at a $670.49 discount relative to an 8-cylinder model. Generally, these discounts decreased over time for one-year old cars though most of the coefficients are not significant and must be considered in that light.

One can conclude from these results that the older the car, the less of the price variation that can be explained by weight and cylinders

Table 5-1

Unweighted Linear Regression Estimates Based Upon Sample(s) of Standard Models

(t-ratios in parentheses)

Dependent Variable[a]	Intercept	CURBWT[b]	D1[c]	D2[c]	R^2
PR(77,78)	1667.54 (1.900)	603.22 (2.768)	-860.28 (-2.023)	-670.49 (-2.464)	.653
PR(77,79)	750.85 (.720)	658.57 (2.544)	-704.51 (-1.395)	-612.64 (-1.895)	.559
PR(77,80)	2056.61 (2.094)	105.51 (.433)	-747.25 (-1.570)	-503.05 (-1.652)	.246
PR(77,81)	1207.43 (1.707)	123.10 (.701)	-234.36 (-.684)	-244.00 (-1.113)	.122
PR(78,79)	1572.17 (1.691)	480.91 (2.034)	-147.95 (-.347)	205.15 (.773)	.453
PR(78,80)	2013.44 (2.840)	90.69 (.503)	151.29 (.465)	302.48 (1.495)	.106
PR(78,81)	1623.31 (2.616)	27.46 (.174)	196.44 (.691)	331.55 (1.875)	.115
PR(79,80)	2257.38 (1.990)	417.56 (1.429)	-385.47 (-.751)	-379.92 (-1.078)	.301
PR(79,81)	1535.60 (1.824)	375.08 (1.729)	-63.60 (-.167)	-94.33 (-.361)	.293
PR(80,81)	2139.50 (2.470)	447.48 (2.039)	-288.22 (-.673)	-173.98 (-.517)	.470

a. The dependent variable PR(v,t) is the price of the particular year v model automobile in year t. These prices are beginning of the year prices, though actual data was obtained on the last week of each of the previous years. For example, PR(77,78) is the price of a car of average condition as published in Ward's Canadian Black Book on Dec. 26, 1977 for a 1977 model car.

b. The variable CURBWT denotes curb weight, measured in 000's of pounds.

c. D1 and D2 are dummy variables for the number of cylinders. If number of cylinders = 4, then D1 = 1, otherwise D1 = 0. If number of cylinders = 6, then D2 = 1, otherwise D2 = 0.

alone. Moreover, all the coefficients for the three and four-year old 1977 built automobiles are insignificant affirming again the lack of explanatory power of the model for older cars.

Table 5-2 presents estimates of the linear model unweighted by market share again, but including as an explanator the interior volume of the automobile. This variable is highly correlated with curb weight in each year and it is this collinearity alone which produces the higher R^2's.

In Tables 5-3 and 5-4, estimates of the unweighted logarithmic models are presented. Comparison between each of these tables with its linear counterpart does not suggest any evidence of a non-linear relationship between automobile prices and characteristics. To the contrary, the linear and logarithmic models performed equally well, or poorly, and appear non-differentiable.

The results presented in Tables 5-5 through 5-8 explicitly take account of the sales share of each model in the market. Unfortunately, market share data is not available for used cars and we were forced to use new car sales as a proxy. For standard type models, this is not too bad an approximation since none of these cars have significantly longer lives (durability) than the others. However, as the age of the sample increases, this assumption becomes more tenuous. In other words, if three percent of the new cars sold in Canada during 1977 were Chevrolet Novas, Novas likely still comprised close to three percent of the stock of 1977 automobiles outstanding in 1978. In 1981, however, it is more likely that Novas no longer comprised three percent of the existing stock of 1977 cars due to specific changes that occurred in this model over time

Table 5-2

Unweighted Linear Regression Estimates Based Upon
Sample(s) of Standard Models
(t-ratios in parentheses)

Dependent Variable	Intercept	CURBWT	VOL[a]	D1	D2	R^2
PR(77,78)	1035.19 (1.210)	1.84 (.006)	171.81 (2.474)	-1171.28 (-2.821)	-993.29 (-3.487)	.709
PR(77,79)	51.08 (.050)	-104.08 (-.281)	217.88 (2.677)	-1098.91 (-2.259)	-1022.01 (3.062)	.639
PR(77,80)	1750.32 (1.700)	-185.78 (-.488)	83.22 (.996)	-897.89 (-1.797)	-659.41 (-1.924)	.268
PR(77,81)	664.26 (.976)	-393.46 (-1.562)	147.58 (2.671)	-501.50 (-1.519)	-521.28 (-2.301)	.282
PR(78,79)	754.58 (.547)	414.07 (1.646)	60.59 (.806)	-7.88 (-.017)	213.83 (.802)	.462
PR(78,80)	1919.00 (1.809)	82.97 (.429)	7.00 .121	167.47 (.471)	303.48 (1.480)	.107
PR(78,81)	1543.82 (1.665)	20.96 (.124)	5.89 (.117)	210.06 (.676)	332.40 (1.854)	.116
PR(79,80)	1687.86 (1.305)	316.01 (1.010)	50.62 (.924)	-295.44 (-.564)	-358.84 (1.014)	.318
PR(79,81)	1057.30 (1.106)	289.80 (1.253)	42.51 (1.049)	12.01 (.031)	-76.63 (-.293)	.315
PR(80,81)	1171.39 (1.386)	190.94 (.885)	97.58 (2.979)	-183.25 (-.473)	-93.82 (-.308)	.582

a. VOL refers to interior volume of automobile. Refer to Table 1 for definitions of other variables.

Table 5-3

Unweighted Logarithmic Regression Estimates Based
Upon Sample(s) of Standard Models
(t-ratios in parentheses)

Dependent Variable	Intercept	CUBRWT	D1	D2	R^2
LPR(77,78)	7.452 (23.424)	.217 (2.745)	-.273 (-1.771)	-.175 (-1.776)	.648
LPR(77,79)	6.960 (13.424)	.294 (2.284)	-.324 (-1.289)	-.210 (1.304)	.537
LPR(77,80)	7.493 (13.736)	.081 (.601)	-.374 (-1.416)	-.236 (-1.396)	.256
LPR(77,81)	7.155 (13.175)	.070 (.519)	-.202 (-.769)	-.194 (-1.153)	.108
LPR(78,79)	7.509 (24.767)	.160 (2.081)	-.062 (-.447)	.074 (.856)	.490
LPR(78,80)	7.616 (26.739)	.034 (.474)	.067 (.511)	.132 (1.625)	.116
LPR(78,81)	7.390 (22.565)	.010 (.120)	.117 (.780)	.189 (2.024)	.129
LPR(79,80)	7.742 (20.964)	.140 (1.471)	-.109 (-.655)	-.103 (-.900)	.306
LPR(79,81)	7.410 (22.373)	.154 (1.803)	-.018 (-.122)	-.029 (-.286)	.309
LPR(80,81)	7.726 (28.127)	.139 (2.004)	-.085 (-.629)	-.047 (-.441)	.466

Refer to previous tables for definition of variables.

Table 5-4

Unweighted Logarithmic Regression Estimates Based
Upon Sample(s) of Standard Models

(t-ratios in parentheses)

Dependent Variable	Intercept	CURBWT	VOL	D1	D2	R^2
LPR(77,78)	7.245 (22.949)	.020 (.175)	.056 (2.189)	-.375 (-2.445)	-.281 (-2.670)	.694
LPR(77,79)	6.603 (12.955)	-.046 (-.242)	.097 (2.345)	-.499 (-2.020)	-3.92 (-2.310)	.605
LPR(77,80)	7.255 (12.882)	-.144 (-.692)	.064 (1.410)	-.491 (-1.796)	-.357 (-1.905)	.300
LPR(77,81)	6.749 (12.841)	-.316 (-1.626)	.110 (2.586)	-.402 (-1.576)	-.401 (-2.294)	.262
LPR(78,79)	7.250 (16.111)	.139 (1.697)	.019 (.783)	-.018 (-.118)	.077 (.882)	.498
LPR(78,80)	7.581 (17.789)	.031 (.404)	.003 (.112)	.073 (.509)	.132 (1.607)	.116
LPR(78,81)	7.360 (15.020)	.008 (.085)	.002 (.081)	.122 (.744)	.189 (1.999)	.129
LPR(79,80)	7.525 (17.984)	.104 (1.026)	.108 (.998)	-.078 (-.458)	-.096 (-.833)	.326
LPR(79,81)	7.206 (19.205)	.117 (1.294)	.018 (1.140)	.014 (.092)	-.022 (-.213)	.334
LPR(80,81)	7.406 (27.947)	.055 (.808)	.032 (3.141)	-.051 (-.418)	-.021 (-.216)	.589

Refer to previous tables for definition of variables.

relative to other 1977 models. Hence, the estimates for one-year old automobiles are likely the most reliable estimates of the weighted regression models.

Table 5-5 presents the estimates of the weighted linear regressions for the sample of standard model automobiles. The weighted coefficients are generally much larger than the unweighted results in Table 5-1 reflecting the greater market share comprised by the heavier cars such as Chevrolet's Chevrolet model, Plymouth's Fury model, and Ford's Ford model, among others.

It is interesting to note that of the four one-year old vehicles examined, D1 is only significant for 1979 and 1980 cars. Moreover, a 4-cylinder car in each of these situations is valued higher with respect to number of cylinders alone, than is an 8-cylinder car. In contrast, for the same one year old models, D2 is significant only for 1977 and 1978 models. For 1977 models, a 6-cylinder car was discounted relative to an 8-cylinder vegucke while for 1978, the 6-cylinder car sold for a premium relative to its 8-cylinder competitor.

While collinearity between the explanatory variables may appear to be problematic in the results presented in Table 5-5 due to weight being correlated, to one degree or another with most other automobile characteristics, this does not seem to be a serious issue here. One sign, for example, of a high degree of multicollinearity is if at, say, the 5 per cent level of significance, the value of the F statistic is significantly different from zero but none of the t statistics for the regression coefficients (other than the constant) is. This would indicate that the separate influence of each of the explanatory variables is weak relative to their joint influence on the dependent variable. This situation is symptomatic of a high degree of multicollinearity, which would prevent us from disentangling the separate influences of the explanatory variables. Each of the regression equations presented in Table 5-5, on the other hand, have F statistics which are significant at the 5 per cent level. Moreover, only one estimated equation, where the dependent variable is PR(77,80), has two coefficients that are not significant at the 5 per cent level. The remaining nine equations have at most one coefficient which is not significant.

Though some collinearity does exist, it does not appear to be harmful. This is further confirmed by examining the R^2's when only CURBWT is used as an explanator. The range of values for R^2 is between .777 and .942, suggesting that weight alone explains most of the variation in prices across automobile models in any year and, thus, minimizing the effects of collinearity when the cylinder dummy variables are included.

Table 5-5

Weighted Linear Regression Estimates Based Upon Sample(s) of Standard Models

(t-ratios in parentheses)

Dependent Variable[a]	Intercept	CURBWT	D1	D2	R^2
PR(77,78)	-7269.70 (-.425)	1054.40 (17.748)	15.01 (.067)	-468.40 (-2.589)	.955
PR(77,79)	31306.00 (-1.584)	939.98 (13.677)	-61.44 (-.237)	-525.28 (-2.509)	.922
PR(77,80)	-4610.42 (-.275)	651.11 (11.186)	209.07 (.951)	-256.51 (1.447)	.892
PR(77,81)	-20834.90 (-1.483)	485.58 (9.942)	462.80 (2.508)	-48.65 (-.327)	.878
PR(78,79)	15834.15 (.682)	877.01 (13.657)	259.42 (1.089)	349.63 (2.031)	.916
PR(78,80)	18190.57 (.886)	580.30 (10.217)	833.16 (3.954)	529.61 (3.478)	.867
PR(78,81)	3016.53 (.173)	466.89 (9.702)	746.46 (4.181)	484.08 (3.752)	.860
PR(79,80)	7668.79 (.432)	986.47 (13.775)	454.45 (2.204)	-72.59 (-.323)	.920
PR(79,81)	3067.02 (.255)	767.67 (15.853)	505.88 (3.627)	129.26 (.850)	.945
PR(80,81)	-4072.26 (-.247)	987.86 (13.043)	613.41 (3.243)	241.83 (1.034)	.946

a. Variables for each model are weighted by their respective share of total sales in 1977. Sales share data were obtained from The Auto Dealer. Refer to previous tables for definition of other variables.

Table 5-6

Weighted Linear Regression Estimates Based Upon Sample(s) of Standard Models

(t-ratios in parentheses)

Dependent Variable	Intercept	CUBRWT	VOL	D1	D2	R^2
PR(77,78)	7170.77 (.488)	-351.21 (-.126)	240.79 (3.957)	-958.92 (-3.103)	-1142.41 (-5.025)	.970
PR(77,79)	-15688.40 (-.897)	-238.55 (-.715)	260.42 (3.590)	-1114.78 (3.027)	-1254.24 (-4.628)	.944
PR(77,80)	7270.35 (.473)	-245.43 (-.837)	198.11 (3.106)	-592.23 (1.829)	-811.05 (-3.404)	.917
PR(77,81)	-6320.10 (-.601)	-609.72 (-3.045)	242.03 (5.557)	-516.15 (-2.334)	-726.12 (-4.462)	.938
PR(78,79)	33582.17 (1.564)	190.81 (.870)	140.08 (3.243)	-348.58 (-1.228)	45.67 (.253)	.935
PR(78,80)	37125.15 (2.095)	-151.75 (-.839)	149.44 (4.192)	184.53 (.788)	205.34 (1.380)	.910
PR(78,81)	20089.43 (1.382)	-193.19 (-1.302)	134.75 (4.608)	161.61 (.841)	191.69 (1.571)	.911
PR(79,80)	27214.56 (1.580)	177.13 (.647)	155.13 (3.044)	-129.97 (-.487)	-364.87 (1.629)	.937
PR(79,81)	16149.87 (1.383)	225.95 (1.218)	103.83 (3.005)	114.70 (.634)	-66.38 (-.437)	.956
PR(80,81)	13551.81 (.847)	420.80 (2.082)	105.03 (2.980)	203.12 (.927)	43.58 (.197)	.957

Refer to previous tables for definition of variables.

Tables 5-7 and 5-8 present the estimates for the weighted logarithmic regressions. It appears that the non-linear models do not perform as well as the linear models in Tables 5-5 and 5-6 as is suggested by the consistently lower R^2's in the semi-logarithmic regression models.

The preceding models were also estimated for the samples consisting of standard North American vehicles supplemented by a set of non-standard automobiles. The samples used in each year are presented in the Appendix to Chapter 4.

Table 5-9 presents the results when the independent variables include weight, dummies for number of cylinders and a dummy differentiating standard and non-standard vehicles. Table 5-10 contains the results when volume is added as an independent variable. Comparing both Tables 5-9 and 5-10 with Tables 5-1 and 5-2, there appears to be no appreciable differences in the R^2's though the weighted coefficients do increase significantly in those equations presented in Tables 5-9 and 5-10 as a result of an increase in the average weight of automobile in that sample relative to the sample of standard vehicles.

Table 5-11 shows the unweighted logarithmic estimates for the supplemented samples and as before, the non-standard dummy variable (D3), is consistently significant and of the expected sign - positive, demonstrating that consumers value this characteristic, perhaps greater quality, embodied in the non-standard vehicles. Table 5-12 presents the estimates of the coefficients when interior volume is included as an explanator. This variable, however, is not significant.

Table 5-7

Weighted Logarithmic Regression Estimates Based Upon Sample(s) of Standard Models

(t-ratios in parentheses)

Dependent Variable	Intercept	CURBWT	D1	D2	R^2
LPR(77,78)	11.487 (124.088)	.0033 (10.240)	-.0002 (-.133)	-.0014 (-1.379)	.879
LPR(77,79)	11.090 (92.273)	.0038 (8.990)	-.0006 (-.390)	-.0019 (-1.488)	.843
LPR(77,80)	11.059 (94.194)	.0032 (7.725)	.0007 (.451)	-.0012 (-.952)	.801
LPR(77,81)	10.629 (93.727)	.0032 (8.216)	.0033 (2.202)	-.0006 (-.512)	.822
LPR(78,79)	11.529 (119.656)	.0028 (10.638)	.0015 (1.504)	.0012 (1.632)	.863
LPR(78,80)	11.313 (110.440)	.0025 (8.729)	.0043 (4.075)	.0021 (2.713)	.813
LPR(78,81)	11.019 (102.059)	.0025 (8.295)	.0049 (4.406)	.0024 (3.018)	.805
LPR(79,80)	11.262 (130.247)	.0037 (10.534)	.0032 (3.207)	.0006 (.569)	.883
LPR(79,81)	11.062 (137.085)	.0036 (10.952)	.0036 (3.786)	.0011 (1.024)	.896
LPR(80,81)	11.425 (120.482)	.0034 (7.726)	.0027 (2.511)	.0007 (.491)	.859

Refer to previous tables for definition of variables.

Table 5-8

Weighted Logarithmic Regression Estimates Based Upon Sample(s) of Standard Models

(t-ratios in parentheses)

Dependent Variable	Intercept	CURBWT	VOL	D1	D2	R^2
LPR(77,78)	11.522 (122.647)	.0007 (.395)	.0006 (1.469)	-.0025 (-1.252)	-.0030 (-2.024)	.886
LPR(77,79)	11.139 (91.949)	.0001 (.033)	.0008 (1.619)	-.0039 (-1.531)	-.0042 (-2.223)	.855
LPR(77,80)	11.115 (95.278)	-.0010 (-.451)	.0009 (1.906)	-.0030 (-1.235)	-.0038 (-2.083)	.821
LPR(77,81)	10.702 (99.817)	-.0022 (-1.084)	.0012 (2.712)	-.0016 (-.707)	-.0040 (-2.402)	.855
LPR(78,79)	11.572 (119.258)	.0012 (1.170)	.0003 (1.752)	.0000 (.002)	-.0004 (1.521)	.874
LPR(78,80)	11.369 (112.422)	.0003 (.303)	.0004 (2.168)	.0024 (1.773)	.0011 (1.300)	.834
LPR(78,81)	11.082 (104.913)	.0000 (.041)	.0005 (2.337)	.0027 (1.953)	.0013 (1.510)	.830
LPR(79,80)	11.274 (119.447)	.0032 (2.119)	.0001 (.339)	.0029 (1.956)	.0004 (.362)	.883
LPR(79,81)	11.067 (125.469)	.0034 (2.397)	.0000 (.150)	.0034 (2.486)	.0010 (.848)	.896
LPR(80,81)	11.438 (110.618)	.0029 (2.245)	.0001 (.350)	.0024 (1.708)	.0005 (.357)	.859

Refer to previous tables for definition of variables.

Table 5-9

Unweighted Linear Regression Estimates Based Upon Sample(s) of All Models

(t-ratios in parentheses)

Dependent Variable	Intercept	CURBWT	D1	D2	D3[a]	R^2
PR(77,78)	-3405.40 (-2.508)	1893.57 (5.972)	1072.29 (1.639)	-102.72 (-.225)	1194.19 (4.195)	.686
PR(77,79)	-4462.51 (-3.045)	1941.18 (5.671)	1402.74 (1.986)	107.97 (.219)	1335.64 (4.350)	.650
PR(77,80)	-2963.91 (-2.107)	1281.27 (3.900)	1377.40 (2.031)	396.02 (.837)	1249.73 (4.240)	.491
PR(77,81)	-3034.46 (2.583)	1129.93 (4.118)	1605.96 (2.836)	500.99 (1.267)	937.09 (3.807)	.456
PR(78,79)	-4742.54 (-2.938)	2018.01 (5.349)	1810.04 (2.519)	176.00 (.398)	1589.41 (3.975)	.486
PR(78,80)	-2842.51 (-2.240)	1287.60 (4.340)	1573.21 (2.784)	237.16 (.682)	1219.19 (3.877)	.365
PR(78,81)	-2449.57 (-2.159)	1013.30 (3.821)	1506.83 (2.983)	339.86 (1.093)	1021.08 (3.633)	.303
PR(79,80)	-4976.91 (-2.225)	1914.56 (4.151)	984.87 (1.182)	-579.85 (-1.084)	2662.52 (2.171)	.405
PR(79,81)	-5755.60 (-2.702)	1909.06 (4.347)	1606.39 (2.025)	-160.91 (-.316)	2405.69 (2.061)	.351
PR(80,81)	-4243.44 (.000)	2026.11 (3.926)	805.16 (.862)	-745.18 (-1.168)	2009.92 (.000)	.323

a. D3 is a dummy variable denoting non-standard and takes on the value 1 for non-standard cars and 0 for standard cars. All other variables are as defined previously.

Table 5-10

Unweighted Linear Regression Estimates Based
Upon Sample(s) of All Models
(t-ratios in parentheses)

Independent Variable	Intercept	CURBWT	VOL	D1	D2	D3	R^2
PR(77,78)	-4056.49 (-2.453)	1758.98 (4.720)	66.72 (.697)	1089.85 (1.656)	-143.55 (-.310)	1202.96 (4.203)	.690
PR(77,79)	-5441.96 (-3.062)	1738.72 (4.343)	100.37 (.976)	1429.16 (2.021)	46.55 (.094)	1348.83 (4.386)	.657
PR(77,80)	-3235.79 (-1.880)	1225.07 (3.159)	27.86 (.280)	1384.73 (2.021)	379.57 (.788)	1253.39 (4.208)	.492
PR(77,81)	-3518.97) (-2.456)	1029.77 (3.189)	49.65 (.599)	1619.04 (2.839)	470.61 (1.173)	943.62 (3.805)	.461
PR(78,79)	-6582.86 (-3.429)	1662.04 (3.903)	189.00 (1.706)	1916.90 (2.700)	94.98 (.217)	1479.27 (3.710)	.511
PR(78,80)	-3711.76) (-2.419)	1119.46 (3.290)	89.27 (1.008)	1623.68 (2.862)	198.89 (.568)	1167.17 (3.663)	.376
PR(78,81)	-3160.65 (-2.301)	875.76 (2.875)	73.03 (.921)	1548.12 (3.049)	308.55 (.985)	978.52 (3.431)	.313
PR(79,80)	-6497.91 (-2.561)	1722.63 (3.559)	133.66 (1.250)	1186.33 (1.404)	-557.78 (-1.047)	2 472.90 (2.011)	.420
PR(79,81)	-7269.88 (-3.013)	1717.98 (3.732)	133.07 (1.308)	1806.96 (2.249)	-138.94 (-.274)	2216.01 (1.895)	.369
PR(80,81)	-3811.42 (.000)	1791.33 (3.142)	137.22 (.971)	929.70 (.986)	-749.04 (-1.172)	-72.58 (.000)	.334

Refer to previous tables for definition of variables.

Table 5-11

Unweighted Logarithmic Regresstion Estimates Based
Upon Sampel(s) of All Models
(t-ratios in parentheses)

Dependent Variable	Intercept	CURBWT	D1	D2	D3	R^2
LPR(77,78)	6.283 (21.094)	.476 (6.846)	.237 (1.652)	.065 (.651)	.363 (5.818)	.758
LPR(77,79)	5.560 (13.693)	.578 (6.104)	.335 (1.719)	.150 (1.113)	.537 (6.385)	.732
LPR(77,80)	5.866 (13.771)	.419 (4.212)	.350 (1.705)	.175 (1.217)	.554 (6.203)	.615
LPR(77,81)	5.455 (12.267)	.440 (4.236)	.546 (2.549)	.195 (1.303)	.519 (5.569)	.572
LPR(78,79)	6.187 (18.575)	.468 (6.009)	.326 (2.202)	.052 (.574)	.411 (4.976)	.593
LPR(78,80)	6.291 (19.593)	.355 (4.731)	.392 (2.739)	.070 (.794)	.411 (5.162)	.453
LPR(78,81)	6.014 (16.654)	.339 (4.016)	.463 (2.880)	.118 (1.189)	.453 (5.062)	.390
LPR(79,80)	6.216 (13.918)	.428 (4.654)	.166 (.997)	-.118 (-1.107)	.615 (2.573)	.487
LPR(79,81)	5.721 (11.997)	.471 (4.793)	.310 (1.745)	-.059 (-.517)	.705 (2.698)	.438
LPR (80,81)	-8.630 (.000)	.385 (4.258)	.058 (.355)	-.151 (-1.350)	15.708 (.000)	.410

Refer to previous tables for definition of variables.

Table 5-12

Unweighted Logarithmic Regression Estimates Based
Upon Sample(s) of All Models

(t-ratios in parentheses)

Dependent Variables	Intercept	CURBWT	VOL	D1	D2	D3	R^2
LPR(77,78)	6.014 (16.556)	.417 (4.651)	.029 (1.287)	.242 (1.646)	.045 (.423)	.365 (5.616)	.750
LPR(77,79)	5.105 (10.483)	.472 (3.919)	.050 (1.683)	.339 (1.720)	.112 (.790)	.539 (6.214)	.730
LPR(77,80)	5.337 (10.755)	.415 (3.214)	.013 (.395)	.384 (1.812)	.195 (1.269)	.574 (6.114)	.611
LPR(77,81)	5.075 (9.352)	.403 (3.016)	.029 (.860)	.583 (2.660)	.205 (1.288)	.540 (5.563)	.579
LPR(78,79)	5.082 (14.654)	.393 (4.480)	.039 (1.729)	.349 (2.383)	.035 (.393)	.388 (4.714)	.613
LPR(78,80)	6.138 (15.742)	.325 (3.762)	.016 (.707)	.401 (2.778)	.063 (.710)	.401 (4.958)	.458
LPR(78,81)	5.784 (13.376)	.312 (3.202)	.014 (.568)	.471 (2.902)	.112 (1.114)	.445 (4.874)	.393
LPR(79,80)	5.895 (11.654)	.388 (4.021)	.028 (1.321)	.208 (1.236)	-.114 (-1.069)	.575 (2.346)	.504
LPR(79,81)	5.336 (9.917)	.423 (4.117)	.034 (1.495)	.361 (2.016)	-.053 (-.473)	.657 (2.521)	.458
LPR(80,81)	-8.535 (.000)	.334 (3.354)	.030 (1.224)	.086 (.520)	-.152 (-1.362)	15.249 (.000)	.425

Refer to previous tables for the definition of variables.

The weighted regressions in Tables 5-13 through 5-16 are provided for completeness only since it is expected that with non-standard vehicles included, there are substantially different durability levels within the sample. Hence, the assumption that the stock of used cars is a reflection of previous new car sales is more tenuous than in the previous estimations using a more homogeneous sample of cars in each year. Reflecting this greater heterogeneity is consistently lower R^2's in all the models presented in Table 5-13 through 5-16 relative to the R^2's obtained with the samples of standard vehicles.

V. Relationship Between Regression Coefficients and Gasoline/Oil Prices

It is now possible to examine the relationship between the hedonic prices of the automobile characteristics relative to the price of gasoline/oil over the time period December 1977 through December 1981. The purpose of this exercise is to see if the prices of these characteristics have been sensitive to changes in the prices of gasoline and oil. Of particular importance is the hedonic price of weight since we know that this variable explains about 80 percent of the variation in miles per gallon (refer to Chapter 4). If changes in fuel prices, therefore, affect the hedonic price of weight, the implication is that the Canadian consumers' purchasing behaviour with respect to automobiles has been influenced by energy prices. Hence, gasoline and domestic oil prices are, as we expect, an important tool of government in trying to encourage energy conservation.

In order to account for the fact that the price of each automobile in the sample has decreased over time due to age, the respective hedonic

Table 5-13

Weighted Linear Regression Estimates Based
Upon Sample(s) of All Models
(t-ratios in parentheses)

Dependent Variable	Intercept	CURBWT	D1	D2	D3	R^2
PR(77,78)	19004.56 (.753)	1031.81 (10.081)	-425.26 (-1.768)	-634.41 (-2.214)	760.41 (2.885)	.851
PR(77,79)	1691.21 (.064)	886.63 (8.188)	-522.46 (-2.066)	-628.92 (-2.088)	839.46 (3.028)	.800
PR(77,80)	10943.95 (.390)	550.80 (4.808)	75.07 (.281)	-83.72 (-.263)	900.59 (3.071)	.662
PR(77,81)	9227.94 (.457)	414.31 (5.036)	122.97 (.640)	-43.25 (-.189)	570.63 (2.709)	.667
PR(78,79)	71631.02 (2.529)	711.37 (7.224)	-570.91 (-2.101)	-460.65 (-2.197)	1125.87 (4.081)	.807
PR(78,80)	68900.91 (3.119)	413.61 (5.386)	-28.78 (-.136)	-174.71 (-1.068)	1035.50 (4.812)	.768
PR(78,81)	51266.33 (2.862)	292.84 (4.703)	68.10 (.396)	-40.84 (-.308)	870.11 (4.987)	.760
PR(79,80)	38573.65 (1.450)	637.90 (2.204)	-743.54 (-1.322)	-871.35 (-2.604)	1858.01 (1.663)	.773
PR(79,81)	38517.94 (1.671)	540.21 (2.154)	-346.62 (-.711)	-526.46 (-1.816)	1218.67 (1.259)	.732
PR(80,81)	67773.98 (1.701)	1109.13 (2.869)	-125.37 (-.183)	-570.46 (-1.384)	74.18 (.052)	.632

Refer to previous tables for definition of variables.

Table 5-14

Weighted Linear Regression Estimates Based
Upon Sample(s) of All Models
(t-ratios in parentheses)

Dependent Variable	Intercept	CURBWT	VOL	D1	D2	D3	R^2
PR(77,78)	18894.76	1038.35	-1.43	-418.84	-630.76	760.89	.851
	(.727)	(3.265)	(-.022)	(-1.096)	(-1.885)	(2.855)	
PR(77,79)	1144.33	919.19	-7.10	-490.50	-610.74	840.23	.800
	(.042)	(2.749)	(-.103)	(-1.221)	(-1.736)	(2.999)	
PR(77,80)	12974.75	429.88	26.38	-43.63	-151.23	897.74	.663
	(.449)	(1.217)	(.362)	(-.103)	(-.407)	(3.033)	
PR(77,81)	9257.29	412.57	.38	121.25	-44.23	570.59	.667
	(.446)	(1.624)	(.007)	(.397)	(-.166)	(2.680)	
PR(78,79)	71458.58	719.62	-1.96	-562.92	-456.42	1129.56	.807
	(2.456)	(2.556)	(-.031)	(-1.503)	(-1.819)	(3.738)	
PR(78,80)	67928.02	460.17	-11.03	16.32	-150.86	1056.28	.768
	(2.995)	(2.096)	(-.227)	(.056)	(-.771)	(4.484)	
PR(78,81)	51629.34	275.47	4.12	51.27	-49.74	862.35	.760
	(2.806)	(1.547)	(.104)	(.217)	(-.313)	(4.513)	
PR(79,80)	41323.18	526.67	47.12	-752. 30	-896.32	1391.78	.774
	(1.525)	(1.544)	(.625)	(-1.330)	(-2.647)	(1.032)	
PR(79,81)	41749.10	409.50	55.37	-356.92	-555.80	670.77	.735
	(1.783)	(1.390)	(.849)	(-.730)	(-1.899)	(.576)	
PR(80,81)	72131.24	1009.72	48.42	-107.02	-584.38	-489.42	.634
	(1.761)	(2.334)	(.525)	(-.155)	(-1.406)	(-.272)	

Refer to previous tables for definition of variables.

Table 5-15

Weighted Log Regression Estimates Based
Upon Sample(s) of All Models
(t-ratios in parentheses)

Dependent Variable	Intercept	CURBWT	D1	D2	D3	R^2
LPR(77,78)	11.564 (140.298)	.00289 (8.595)	-.00142 (-1.814)	-.00080 (-.860)	.00365 (4.244)	.845
LPR(77,79)	11.213 (104.865)	.00304 (6.980)	-.00213 (-2.095)	-.00073 (-.598)	.00506 (4.531)	.805
LPR(77,80)	11.141 (104.139)	.00237 (5.433)	-.00054 (-.530)	-.00050 (.412)	.00533 (4.772)	.765
LPR(77,81)	10.860 (96.904)	.00244 (5.344)	-.00057 (.531)	-.00021 (.163)	.00441 (3.771)	.730
LPR(78,79)	11.756 (125.331)	.00221 (6.776)	-.00102 (-1.139)	-.00114 (-1.647)	.00321 (3.515)	.775
LPR(78,80)	11.583 (127.380)	.00175 (5.524)	.00045 (.517)	-.00060 (-.894)	.00361 (4.079)	.745
LPR(78,81)	11.346 (117.759)	.00155 (4.630)	.00071 (.770)	-.00032 (-.446)	.00398 (4.236)	.720
LPR(79,80)	11.444 (124.962)	.00245 (2.455)	-.00058 (-.301)	-.00192 (-1.666)	.00549 (1.429)	.785
LPR(79,81)	11.286 (117.378)	.00230 (2.202)	-.00014 (-.068)	-.00157 (-1.296)	.00526 (1.304)	.753
LPR(80,81)	11.746 (103.603)	.00345 (3.133)	.00113 (.579)	-.00083 (-.704)	-.00072 (-.177)	.653

Refer to previous tables for definition of variables.

Table 5-16

Weighted Logarithmic Regression Estimates Based Upon Sample(s) of All Models (t-ratios in parentheses)

Dependent Variable	Intercept	CURBWT	VOL	D1	D2	D3	R^2
LPR(77,78)	11.553 (136.694)	.00353 (3.412)	-.00014 (-.652)	-.00080 (-.643)	-.00045 (-.413)	.00367 (4.235)	.847
LPR(77,79)	11.201 (102.069)	.00379 (2.825)	-.00016 (-.589)	-.00140 (-.868)	-.00031 (-.218)	.00508 (4.515)	.806
LPR(77,80)	11.136 (101.131)	.00270 (2.002)	-.00007 (-.256)	-.00022 (-.136)	.00068 (0.481)	.00534 (4.731)	.765
LPR(77,81)	10.853 (94.123)	.00286 (2.029)	-.00009 (-.314)	.00098 (.577)	.00044 (0.297)	.00442 (3.743)	.731
LPR(78,79)	11.755 (121.988)	.00222 (2.386)	-.0000036 (-.018)	-.00101 (-.814)	-.00114 (-1.367)	.00322 (3.217)	.775
LPR(78,80)	11.576 (124.095)	.00209 (2.310)	-.00008 (-.401)	.00078 (.649)	-.00043 (-.533)	.00377 (3.887)	.745
LPR(78,81)	11.340 (114.664)	.00182 (1.902)	-.00006 (-.301)	.00097 (.764)	-.00018 (-.212)	.00410 (3.988)	.721
LPR(79,80)	11.448 (122.388)	.00228 (1.938)	.00007 (.266)	-.00060 (-.305)	-.00195 (-1.673)	.00480 (1.033)	.785
LPR(79,81)	11.291 (115.004)	.00209 (1.695)	.00009 (.323)	-.00015 (-.075)	-.00161 (-1.315)	.00439 (0.899)	.753
LPR(80,81)	11.760 (100.976)	.00314 (2.551)	.00015 (.570)	.00119 (.605)	-.00087 (-.735)	-.00247 (-.481)	.655

Refer to previous tables for definition of variables.

prices are divided by the average car price in year t. Moreover, the price of gasoline is measured by the Gasoline for Autos and Trucks Index published by Statistics Canada (62-010). Hereafter, this index is referred to as the GPI. To express gasoline price changes in real terms, GPI was deflated by the Consumer Price Index (CPI), also found in Statistics Canada 62-010. Moreover, domestic oil prices, defined as the refiners acquisition price of light crude oil at Edmonton, were obtained from Data Resources Inc. World oil prices are for Saudi Arabian light crude oil and were obtained from Esso Facts and Figures. Both oil prices were deflated by the CPI with 1977 as the base year.

The relationship between the adjusted hedonic price of weight and the real prices of gasoline, domestic oil, and world oil are presented in Table 5-17. In this analysis we have used the weighted linear hedonic prices of the weight variable shown in Table 5-5. These estimates are selected since market share information should be incorporated in the coefficient estimates and the model explains more variation in prices across vehicles than does the logarithmic model. Furthermore, the results presented in Table 5-5 do not suffer the same high degree of collinearity observed in the equations in Table 5-6.

For the one-year old models presented in the first part of Table 5-17, there is a strong relationship between the hedonic price of weight and both real gasoline and domestic oil prices. An increase in gasoline prices, for example, consistently resulted in a decrease in the value attached to weight and vice versa. For two-year old cars, as represented by the middle group, there appears to be no meaningful relationship between energy prices and the value attached to vehicle weight.

Table 5-17

Relationship Between Gasoline/Oil Prices and the Hedonic Price of Weight

Date	Vintage	Hedonic Price of CURBWT/Average Price of Automobile in t[a]	GPI_t/CPI_t[b]	$DOP_t/CPI_t(\$)$[c]	$WOP_t/CPI_t(\$)$[d]
Dec. 1977	1977	3.233	1.285	10.75	14.00
		-	+	+	+
Dec. 1978	1978	2.662	1.354	11.76	14.67
		+	-	-	+
Dec. 1979	1979	3.243	1.300	11.55	25.46
		-	+	+	+
Dec. 1980	1980	2.750	1.460	14.37	28.70
Dec. 1978	1977	3.676	1.354	11.76	14.67
		-	-	-	-
Dec. 1979	1978	2.202	1.300	11.55	25.46
		+	+	+	+
Dec. 1980	1979	3.079	1.460	14.37	28.70
Dec. 1979	1977	3.129	1.300	11.55	25.46
		-	+	+	+
Dec. 1980	1978	2.264	1.460	14.37	28.70

a. Since the weights are absolute numbers of cars sold of each model, the weighted average prices are in the magnitude of 10^5 power. The figures in this column are, therefore, measured in powers of 10^{-3}.

b. Gasoline Price Index in t divided by the Consumer Prize Index in t.

c. Domestic Oil Price in t divided by the Consumer Prize Index in t.

d. World Oil Price in t divided by the Consumer Prize Index in t.

Moreover, the apparently correct relationship for three-year old cars is likely only spurious. The lack of relationship for cars two years or older is probably due to the assumption of market share in any year for used cars being a reflection of earlier sales of those cars when they were new. For one-year old vehicles, however, this assumption is less critical. It is noteworthy, moreover, that the results for one-year old vehicles are consistent as well as intuitively appealing.

When the relationship between gasoline prices and the hedonic prices associated with the number of cylinders is examined, the results are again encouraging as can be seen in Table 5-18. Because many of the hedonic prices are non-significant, one must interpret these results with care. Looking to the D1 variable for one-year old cars, in both December 1977 and December 1978, a 4-cylinder car neither sold at a discount nor premium over an 8-cylinder car since the coefficients in these years are not significant. However, in both December 1979 and December 1980, a 4-cylinder car actually sold at a premium relative to an 8-cylinder car based upon this particular characteristics alone. This is consistent with the upward trend in gasoline and domestic oil prices over this period. One can go further and try to explore the specific inconsistency between December 1978 and December 1979 when the hedonic price associated with D1 increased even though domestic energy prices decreased. This enigma might simply be resolved by the sharp increase in real world oil prices at the time and Canadian consumers believing that domestic prices would have to rise in the future as a result of the dramatic increase in world oil prices. Their response when purchasing automobiles during that period may simply have

Table 5-18

Relationship Between Gasoline/Oil
Prices and the Hedonic Prices of D1 and D2

Date	Vintage	Hedonic Price of D1/Average Price of Auto in t[a]	Hedonic Price of D2/Average Price of Auto in t[a]	GPI_t/CPI_t	DOP_t/CPI_t($)	WOP_t/CPI_t($)
Dec. 1977	1977	.046*	-1.436	1.285	10.75	14.00
		+	+	+	+	+
Dec. 1978	1978	.787*	1.061	1.354	11.76	14.67
		+	-	-	-	+
Dec. 1979	1979	1.494	- .239*	1.300	11.55	25.46
		+	+	+	+	+
Dec. 1980	1980	1.708	- .673*	1.460	14.37	28.70
Dec. 1978	1977	-.240*	-2.054	1.354	11.76	14.67
		+	+	-	-	+
Dec. 1979	1978	3.161	2.009	1.300	11.55	25.46
		-	-	+	+	+
Dec. 1980	1979	2.029	.518*	1.460	14.37	28.70
Dec. 1979	1977	1.005*	-1.233*	1.300	11.55	25.46
		+	+	+	+	+
Dec. 1980	1978	3.620	2.348	1.460	14.37	28.70

* Not significant.

a. Values are measured in power 10^{-3}.

been a reaction to the wide discrepancy between domestic and world prices and their expectations that domestic prices would increase as a result of this growing price disparity.

Examination of the variable D2 shows that in December 1977, a 6-cylinder vehicle sold at a discount relative to an 8-cylinder car. At December 1978, the discount for a 6-cylinder engine became a premium. During the same period, energy prices increased. As of December 1979, there was virtually no significant difference in the value attached to a 6 versus 8-cylinder car and again this change (decrease in hedonic price) was consistent with the decrease in real domestic energy prices during that period. In December 1980, the hedonic price associated with a 6-cylinder vehicle was again positive, though insignificant, while real energy prices also increased.

It is reasonable to conclude that consumers have generally reacted to real domestic energy prices in a rational manner in deciding the value they attached to engine size when purchasing an automobile.

While confirmation of the results outlined in Tables 5-17 and 5-18 must await additional data and analysis, one can gain some further insight presently, however, by looking to dealers in the second-hand market and determining the value they attach to particular automobile characteristics that effect energy efficiency, e.g., air conditioning, automatic transmission, and number of cylinders. Presumably, the values assigned to these characteristics in the used car market are reflecting a knowledgeable group's assessment of consumers' preferences.

The data appearing in Tables 5-19 through 5-24 were collected from Ward's Canadian Black Book and represent values suggested to dealers for the respective characteristics. We concentrated on two periods, December 1978-79 and December 1979-80. The first period was the only one in which the real price of gasoline decreased while the second period showed the most dramatic increase in the real price of gasoline for the available data. For each of these periods we examined the assigned value of the particular characteristic for both one-year old and two-year old vehicles.

Tables 5-19 through 5-21 refer to the period December 1978-79 when the real price of gasoline decreased. Notice that throughout the analysis, two-year old cars at December 1978 are compared to two-year old cars as of December 1979. Moreover, one-year old cars at December 1978 are compared to one-year old cars at December 1979. This was done to minimize the effect of a change in the value of a characteristic principally due to the car being a year older.

One would expect that during the period in which the real price of gasoline fell (December 1978-79), the premium paid for air-conditioning[3] would rise. Table 5-19 generally concurs with this expectation.

It should also be the case that the premium paid for automatic transmission should rise with a decrease in real gasoline prices. Table 5-20, however, is quite ambivalent as to both the direction and magnitude of the change. While it appears that the general trend for two-year old cars is for the premium to decrease, the trend for one-year old cars is for the premium to increase. In both cases, the changes are, however, quite small.

Table 5-19

Value of Air-Conditioning
(Prices 1979=100)

Model	Two-Year Old Vehicles 1977 Vintage Dec. 1978 Char. Values	Two-Year Old Vehicles 1978 Vintage Dec. 1979 Char. Values	One-Year Old Vehicles 1978 Vintage Dec. 1978 Char. Values	One-Year Old Vehicles 1979 Vintage Dec. 1979 Char. Values
Pacer	338	400	366	450
Skyhawk	338	400	366	450
Skylark	338	400	366	450
Century	338	450	394	500
Chevette	366	350	338	400
Monza	338	400	366	450
Nova	338	400	366	450
Camaro	366	450	394	500
Malibu	366	450	394	500
Monte Carlo	366	450	394	500
Chevrolet	366	450	394	500
Cordoba	366	450	394	500
Chrysler	366	450	394	500
Aspen	338	400	366	450
Pinto	309	350	338	400
Granada	338	400	366	450
Thunderbird	366	450	394	500
Bobcat	309	350	338	400
Monarch	338	400	366	450
Cougar	366	450	394	500
Omega	338	400	366	450
Delta 88	366	450	394	500
Volare	338	400	366	450
Sunbird	338	400	366	450
Le Mans	366	450	394	500

Table 5-20
Value of Automatic Transmission
(Prices 1979=100)

Model	Two-Year Old Vehicles 1977 Vintage Dec. 1978 Char. Values	Two-Year Old Vehicles 1978 Vintage Dec. 1979 Char. Values	One-Year Old Vehicles 1978 Vintage Dec. 1978 Char. Values	One-Year Old Vehicles 1979 Vintage Dec. 1979 Char. Values
Pacer	422	400	450	450
Skyhawk	422	400	450	450
Skylark	422	400	450	450
Century	450	450	478	500
Chevette	422	350	450	400
Monza	422	400	450	450
Nova	422	400	450	450
Camaro	450	450	478	500
Malibu	450	450	478	500
Monte Carlo	N/A	450	478	500
Aspen	422	400	450	450
Granada	422	400	450	450
Monarch	422	400	450	450
Omega	422	400	450	450
Volare	422	400	450	450
Sunbird	422	400	450	450
Le Mans	450	450	478	500

Table 5-21 presents the data on the premium paid for two additional cylinders. As real gasoline prices decrease, it is expected that the value of additional cylinders would increase. The evidence, however, clearly contradicts our intuition.

Aside from air-conditioning, the value suggested to used car dealers for automatic transmission and the number of cylinders in a vehicle do not correspond to the expectations one would derive from the decrease in gasoline prices.

When real gasoline prices increased during the December 1979-80 period, Table 5-22 shows that the premium for air-conditioning decreased in both two-year old and one-year old vehicles. Moreover, Table 5-23 illustrates that the premium suggested for automatic transmission decreased, as we would expect to be the case. Finally, Table 5-24 shows that the premium for additional cylinders also reacted to the increase in real gasoline prices in the expected direction.

Generally, the suggested value of the characteristics seem to have followed the changes in real energy prices except for the cylinder premium during the 1978-79 period of declining gasoline prices which acted contrary to what might have been expected. This counterintuitive result may be attributed to dealers' expectations that the fall in gasoline prices was only temporary in which case they were reacting to expected future higher prices when valuing the premium for engine size. Similar logic, however, does not explain the intuitively appealing results for air-conditioning over the same period unless there is a weaker perceived relationship between energy efficiency and engine size than there is between energy efficiency

Table 5-21

Value of Two Additional Cylinders
(Prices 1979=100)

Model	Std. No. of Cyl.	Two-Year Old Vehicle: 1977 Vintage Dec.1978 Char. Values	Two-Year Old Vehicle: 1978 Vintage Dec. 1979 Char. Values	One-Year Old Vehicles: 1978 Vintage Dec. 1978 Char. Values	One-Year Old Vehicles: 1979 Vintage Dec. 1979 Char. Values
Skylark	8	0	0	0	0
Century	8	169	0	225	0
Monza	6	309	100	338	100
Nova	8	0	0	0	0
Camaro	8	281	0	309	0
Malibu	8	169	0	225	0
Monte Carlo	8	N/A	0	225	0
Chevrolet	8	225	100	225	100
Aspen	8	0	0	0	0
Pinto	4	253	100	281	100
Granada	8	0	0	0	0
Bobcat	4	253	100	281	100
Monarch	8	0	0	0	0
Omega	8	0	0	0	0
Delta 88	8	N/A	100	N/A	100
Volare	8	0	0	0	0
Sunbird	6	309	100	338	100
Le Mans	8	169	0	225	0

Table 5-22

Value of Air-Conditioning
(Prices 1979=100)

Model	Two-Year Old Vehicle 1978 Vintage Dec.1979 Char. Values	Two-Year Old Vehicle 1979 Vintage Dec. 1980 Char. Values	One-Year Old Vehicles 1979 Vintage Dec. 1979 Char. Values	One-Year Old Vehicles 1980 Vintage Dec. 1980 Char. Values
Pacer	400	349	450	392
Skyhawk	400	349	450	392
Skylark	400	349	450	392
Century	450	392	450	436
Chevette	350	349	500	392
Monza	400	349	400	392
Camaro	450	392	500	436
Malibu	450	392	500	436
Monte Carlo	450	392	500	436
Chevrolet	450	392	500	436
Cordoba	450	392	500	436
Chrysler	450	392	500	436
Aspen	400	349	450	392
Pinto	350	349	400	392
Granada	400	349	450	392
Thunderbird	450	392	500	436
Bobcat	350	349	400	392
Monarch	400	349	450	392
Cougar	450	392	500	436
Omega	400	349	450	392
Delta 88	450	392	500	436
Volare	400	349	450	392
Sunbird	400	349	450	392
Le Mans	450	392	500	436

Table 5-23

Value of Automatic Transmission
(Prices 1979=100)

Model	Two-Year Old Vehicle: 1978 Vintage Dec. 1979 Char. Values	Two-Year Old Vehicle: 1979 Vintage Dec. 1980 Char. Values	One-Year Old Vehicles: 1979 Vintage Dec. 1979 Char. Values	One-Year Old Vehicles: 1980 Vintage Dec. 1980 Char. Values
Pacer	400	349	450	392
Skyhawk	400	305	450	349
Skylark	400	349	450	392
Century	450	392	500	436
Chevette	350	262	400	305
Monza	400	305	450	349
Camaro	450	349	500	392
Malibu	450	392	500	436
Aspen	400	349	450	392
Granada	400	349	450	392
Monarch	400	349	450	392
Omega	400	349	450	392
Volare	400	349	450	392
Sunbird	400	305	450	349
Le Mans	450	392	500	436

Table 5-24

Value of an Addditional Two Cylinders
(Prices 1979=100)

Model	Std. No. of Cyl.	Two-Year Old Vehicle: 1978 Vintage Dec.1979 Char. Values	Two-Year Old Vehicle: 1979 Vintage Dec. 1980 Char. Values	One-Year Old Vehicles: 1979 Vintage Dec. 1979 Char. Values	One-Year Old Vehicles: 1980 Vintage Dec. 1980 Char. Values
Skylark	8	0	0	0	0
Century	8	0	0	0	0
Monza	6	100	87	100	87
Camaro	8	0	0	0	0
Malibu	8	0	0	0	0
Monte Carlo	8	0	0	0	0
Chevrolet	8	100	87	100	87
Aspen	8	0	0	0	0
Pinto	4	100	87	100	0
Granada	8	0	0	0	0
Bobcat	4	100	87	100	0
Monarch	8	0	0	0	0
Omega	8	0	0	0	0
Delta 88	8	100	87	100	87
Volare	8	0	0	0	0
Sunbird	6	100	87	0	87
Le Mans	8	0	0	0	0

and air conditioning.

It is reasonable to conclude that the suggested premiums for these characteristics are generally consistent with our expectations given the changes in energy prices and, furthermore, consistent with the results obtained using an hedonic pricing approach. Consumers have been strongly influenced in the type of automobile purchased by changes in gasoline prices. Higher energy prices have induced consumers to purchase lighter, more energy efficient automobiles. An important question, however, remains unanswered. As automobiles become increasingly lighter, they become increasingly unlikely to withstand greater impact in the event of an accident. Hence, there is a tradeoff between the savings associated with more energy efficient vehicles and safety lost with such vehicles. At some point, given the present technology, safety will become dominant and the lower bound of energy savings will be close to realization unless a new automobile technology is born.

Chapter Six:

THE SUPPLY AND DEMAND FOR DURABLE GOODS IN AN UNCERTAIN TECHNOLOGICAL ENVIRONMENT

I. Introduction

Most textbooks concerned with the theory of the firm neglect an important variable under the firms' control, namely the type of product to be produced. Just as the presence or absence of competition affects the price/output decisions, so one might expect industrial structure to affect the product choice. Until quite recently, however, little formal analysis of the firms' product quality (durability) determination was to be found in the literature. The exception to this early oversight was a study by Wicksell (1934). The recent literature, on the other hand, began in the 1960's with the work of Martin (1962), Kleiman and Ophir (1960), Levhari and Srinivasan (1969), and Schmalensee (1970). These authors generally concluded that a monopoly would produce goods of less durability than a competitive industry with equivalent cost conditions. Then, in a pair of studies, Swan (1970, 1971) showed that this conclusion did not follow and that durability choice was independent of market structure given the assumptions made in these studies.

Swan's independence results suprised economists due to its counter-intuitive nature. Moreover, Swan's work has provided the point of departure for most of the subsequent studies which are reviewed in Schmalensee's (1979) survey paper. In writing this paper, Schmalensee categorizes the post-Swan literature in the area according to which of the Swan assumptions are being relaxed. Specifically, the model developed by Swan assumed:

(i) constant returns to scale;

(ii) exogenous depreciation of the capital stock;

(iii) flow of services generated from the capital stock proportional to the stock on hand;

(iv) perfect knowledge and perfect foresight;

(v) perfect capital markets;

(vi) no taxes or transactions costs; and

(vii) no demand for durability per se.

We shall not attempt here to reproduce the fine job done by Schmalensee in bringing this diverse literature together, but will, instead, concentrate on those papers which have particular relevance to this study. Our concern in this section of the project is with the generalizations inferred within these prior studies on product durability. First, it is generally implied that a more durable good is always preferred by consumers to a less durable good and a firm that restricts this attribute in building its product imputes some cost upon society. Secondly, the question of whether or not industry structure affects the durability of the good produced neglects the fundamental issue of how the industry arrived at the particular market structure in the first place. If there were no, or negligible, entry barriers and significant rents to be achieved, a competitive industry would have evolved. On the other hand, significant rents and barriers to prevent competitors from entering the industry would have resulted in a more monopolistic industry. The relevance of this industry evolution is that the type of product offered in the market (i.e. product durability) may very well be a barrier that discourages other firms from entering the market. As such, durability of the product produced may be a primary cause of this observed structure of the industry and not the result of assuming one particular structure or another as has been the practice in previous studies of this problem.

Our specific concern is the durability of a consumer good that requires both an initial outlay as well as continuing outlays for a variable input which is required to produce the services of the durable good throughout its life. Examples of such goods are automobiles, residential heating modes, and refrigerators, among others. The analysis examines both the demand for durability and the supply of durability by producing firm(s).

II. Demand for Consumer Durables and Durability

A. Assumptions

Four basic assumptions are utilized throughout the analysis. First, the durable good exhibits a one-hoss shay pattern of depreciation. That is, it provides a constant flow of services for its known lifetime and then becomes useless. While this assumption greatly simplifies the exposition, it does not appear that the qualitative results are sensitive to the depreciation pattern chosen.[1] Second, we assume that the flow of services from the durable good is proportional to the stock of the durable good. While this has been the assumption made in most previous studies, there have been notable exceptions. The first attempt to relax this assumption was made by Parks (1974). In that paper, Parks assumed that owning a good with a specified lifetime involves an operating cost outlay in order to maintain the service flow at some constant level. Under constant returns, however, the model yields the Swan result that durability is independent of market structure. A formally more complicated model was considered by Epple and Zelenitz (1975). In the general case, a new unit of the good is assumed to be endowed with two characteristics: built-in durability and operating efficiency. The owner of the good can choose the intensity of use, i.e. the ratio of service flow to stock. This decision, in turn, affects both the actual depreciation and operating cost. The basic conclusion derived is that if the producing firm is a monopolist, the consumer's control of one input imposes a constraint that generally distorts his durability choice from that which would be chosen under competitive conditions.

The third assumption made is that once the durable good is purchased, the resulting flow of services is always replaced at the end of the asset's life by the purchase of another unit of the durable providing the same service each period over its lifetime. This is both an assumption made for expositional convenience and ease of comparability with prior studies. While it may appear that this assumption is highly restrictive, for the type of goods being examined, it is probably quite reflective of their particular nature. That is, refrigeration is a required service that is met by the continual replacement of one's refrigerator. Similarly, heating is a service that is required on a continuing basis and achieved through replacement of the durable good. For automobiles, the service most consistent with this assumption is non-discretionary driving miles.

The final assumption is that of a representative consumer. The model concentrates on a single durable good so we need not be too concerned by the argument that the representative consumer concept is not capable of explaining the existence of different types (e.g. models) of a good.

B. Notation

The following notation is utilized throughout the analysis:

$Y(t)$: Consumer's income in period t ;

$C(t)$: Consumption of the perishable good in t ;

$Q(t)$: Flow of services from the stock of consumer durables. Since the flow is assumed proportional to the stock, both can be represented by $Q(t)$;

$p_c(t)$: Price of perishable good in t ;

$p_d(t)$: Price of durable good in t ;

$p_v(t)$: Price of variable input in t which is used to derive the services generated from the durable good;

$I(t)$: Gross purchases of the durable good;

$E(t)$: Operating efficiency of the durable good;

$G[p_v(t)/E(t)]$: Operating cost per unit of service consumed from the durable good, where $\frac{\partial G}{\partial E} < 0$ and $\frac{\partial G}{\partial p_v} > 0$;

T: Durability (lifetime) of the durable good;

r: Consumer's rate of time preference; and

ξ: Opportunity cost of funds.

C. Model

Consider a consumer at a point in time $t=0$ who must choose an optimal consumption and investment path for his indefinite future. The consumer's decisions are made with the goal of maximizing an intertemporal utility function where

$$(6\text{-}1) \qquad U = U[C(t), Q(t), T]$$

That is, the consumer derives utility from the consumption of the services generated from both the perishable and durable goods as well as the durability (quality) of the durable good purchased.

The consumer's lifetime wealth constraint can be written as:

$$(6\text{-}2) \qquad W = \int_0^\infty Y(t)e^{-rt}dt$$

since wealth is simply the sum of the discounted income flows to the consumer over his lifetime.[2] Assuming capital markets are organized so as to provide both borrowing and lending over the consumer's lifetime, his present wealth can be equated to the present value of his lifetime expenditures, i.e.

$$(6\text{-}3) \qquad W = \int_0^\infty [C(t)p_c(t) + I(t)[p_d(t) + G(t)]]e^{-rt}dt$$

where $G(t)$ is equivalent to $G[p_v(t)/E(t)]$.

The first term on the R.H.S. of equation (6-3) represents the consumer's expenditures on the perishable good while the second term is his expenditures on the durable good. While it may be argued, and correctly so, that the price of a durable good incorporates all product characteristics and their associated implicit prices, the distinction is made here between the operating and non-operating characteristics in order to recognize the consumer's choice problem. Essentially, we are assuming that p_d is the part of the price paid for the durable good which encompasses all the characteristics of the good aside from the operating characteristics which are included within G. The sum of p_d and G yield the actual price paid for each unit of the durable good purchased in very much the same manner of hedonic pricing.

The stock of the durable asset (or flow of services at any point in time) is simply the sum of the amounts put into place during the prior interval of length T, or

$$Q(t) = \int_{t-T}^{t} I(t)dt \tag{6-4}$$

Moreover, because of the assumed replacement policy, the gross investment (i.e. net additions to the stock plus replacement investment) can be expressed as:

$$I(t) = \dot{Q}(t) + I(t-T)\text{ , or}$$

$$I(t) = \dot{Q}(t) + \dot{Q}(t-T) + \dot{Q}(t-2T) + \ldots \tag{6-5}$$

where dots represent time derivaties, e.g. $\dot{Q}(t) = \frac{d(Q)}{dt}$, and have the interpretation of net additions to the stock of durables.

After substituting equation (6-5) into the wealth constraint in (6-3), the problem can now be formally expressed:

$$\text{(6-6)} \qquad \underset{C(t),Q(t),T}{\text{Max}} \int_0^\infty U[C(t),Q(t),T]e^{-\xi t}dt$$

$$\text{s.t.} \quad W = \int_0^\infty [C(t)p_c(t) + [\dot{Q}(t)+\dot{Q}(t-T)+\ldots][p_d(t)+G(t)]]e^{-rt}dt$$

The solution to this problem is a straightforward application of calculus of variation techniques. To do so, however, requires slight modification of the above problem so that it is in suitable form for applying the Euler-Lagrange equation.[3]

First, we take the derivative of the wealth constraint with respect to t, where $\dot{W}$ is the change in wealth over time. The problem can then be expressed in Lagrangian form as:

$$\text{(6-7)} \qquad \text{Max} \int_0^\infty \{U[C(t),Q(t),T]e^{-\xi t} + \lambda(t)[\dot{W}-C(t)p_c(t) - [\dot{Q}(t)+\dot{Q}(t-T)+\ldots][p_d(t)+G(t)]]e^{-rt}\}dt$$

where $\lambda(t)$ represents the Lagrangian multiplier in t and can be interpreted as the marginal utility of an additional dollar of income in t.

Consider now the general term in (6-7),

$$\text{(6-8)} \qquad S_n = \int_0^\infty \lambda(t)[p_d(t)+G(t)]\dot{Q}(t-nT)e^{-rt}dt$$

for any value of n. Let $s = t-nT$, so that $t = s+nT$ and $ds = dt$. Substituting into S_n, we have

$$(6\text{-}9) \qquad S_n = e^{-rnT} \int_0^{\infty} \lambda(s+nT)[p_d(s+nT) + G(s+nT)]\dot{Q}(s)e^{-rs}ds$$

Thus, after redefining s to equal t, the problem outlined in (6-7) can be written as:

$$(6\text{-}10) \qquad \underset{\langle C(t),Q(t),T\rangle}{\text{Max}} \int_0^{\infty} \Phi(C,T,\dot{W},\dot{Q},Q)dt$$

where

$$\Phi = U[C(t),Q(t),T]e^{-\xi t} + \lambda\{[\dot{W}-C(t)p_c(t)]$$

$$- \sum_{n=0}^{\infty} e^{-rnT}[p_d(t+nT) + G(t+nT)]\dot{Q}(t)\}e^{-rt}$$

Notice that in this problem the Lagrange multiplier is constant in each period since $\dot{\lambda} = 0$ as implied by $\frac{\partial\Phi}{\partial\dot{W}} = 0$, one of the necessary Euler conditions for an optimal solution.

We are now in a position to simply apply Euler's equation to the revised problem in (6-10).

$$(6\text{-}11a) \qquad \frac{\partial\Phi}{\partial C(t)} - \frac{d}{dt}\left(\frac{\partial\Phi}{\partial\dot{C}(t)}\right) = U_{C(t)}e^{-\xi t} - \lambda p_c(t)e^{-rt} = 0$$

$$(6\text{-}11b) \qquad \frac{\partial\Phi}{\partial Q(t)} - \frac{d}{dt}\left(\frac{\partial\Phi}{\partial\dot{Q}(t)}\right) = U_{Q(t)}e^{-\xi t} - \lambda \sum_{n=0}^{\infty} e^{-r(t+nT)}[r[p_d(t+nT)$$

$$+ G(t+nT)] - \dot{p}_d(t+nT) - \dot{G}(t+nT)] = 0$$

$$(6\text{-}11c) \quad \frac{\partial \Phi}{\partial T} - \frac{d}{dt}\left(\frac{\partial \Phi}{\partial \dot{T}}\right) = U_T e^{-\xi t} - \lambda \sum_{n=0}^{\infty} e^{-r(t+nT)}\left[\frac{\partial p_d(t+nT)}{\partial T}\right.$$

$$\left. - rnp_d(t+nT) - rnG(t+nT)\right]\dot{Q}(t) = 0$$

where the subscripts attached to the U's denote partial derivatives, e.g. $U_{C(t)}$ is the marginal utility to the consumer from additional consumption of the perishable good.

Equation (6-11a) states that the perishable good should be consumed in any period in an amount such that the discounted marginal utility of the last unit of the good consumed is proportional to its discounted price, where the factor of proportionality is the consumer's marginal utility of income. Equation (6-11b) provides a similar decision rule for consumption of the durable good. Optimal consumption in any period occurs at the point where the discounted marginal utility of the last unit consumed of the durable good with a lifetime of T periods is proportional to the discounted forward price of that unit. The forward price, moreover, incorporates both future replacement cost of the durable good and future operating costs associated with consumption of the services of the good.

Finally, equation (6-11c) represents the consumer's durability choice. Optimal durability of the non-perishable good is where the discounted marginal utility from the last unit of durability is proportional to its discounted cost. The $\frac{\partial p_d(t)}{\partial T}$ term requires some explanation, particularly when the industry is assumed competitive. This term is the increase in price of the durable good to the consumer caused by an increase in the demand for durability of the product. While firms in a competitive industry are unable, by definition, to differentiate their product and price accordingly, it is assumed here that the increase in required durability is concomitantly reflected in the production of the good by all firms in the industry. This is consistent, as well, with the concept of a representative consumer desiring a particular level of durability so that product differentiation based upon this attribute would never be practiced. As required durability increases, the price of the good increases to reflect the increased cost to the firm and perhaps even some economic rent depending upon the particular industry structure.

Moreover, it can also be seen in equation (6-11c) that as the durability increases, replacement is postponed which, in turn, reduces the discounted marginal cost of durability. Furthermore, if the price of the durable good is expected to increase over time, this savings (i.e. reduction in discounted marginal cost) is even greater from purchasing a good today with a longer life.

On the other side, however, is the expected future change in operating costs of the durable good in equation (6-11c). Recall that

$$G(t+nT) = G[p_v(t+nT)/E(t+nT)] \quad . \qquad (6\text{-}12)$$

If the efficiency embodied in new goods in the future is expected to increase faster than the price of the variable input (e.g. gasoline, electricity, natural gas, etc.), the expected operating cost associated with new units of the durable is falling over time. A consumer would prefer, _ceteris paribus_, not to hold a good with a long life, but instead would prefer a good of lower durability so as to be in a position to purchase the more efficient good as it comes on stream.[4]

The conclusion that consumers may prefer a good of lower durability, given their expectations of future variable input costs and technological change, is contrary to the generally accepted view that a more durable product is always preferred to a less durable one, ceteris paribus. This belief has been implicit in previous studies[5] which have compared the levels of durability provided by monopolistic and competitive producers. The particular relevance of this result to this study which addresses the energy efficiency characteristics of automobiles is that given potential (or expected) technological advances that might increase automobile efficiency, it is not necessarily in the consumer's interest for producers to build cars that last too long a time. Hence, the charge that automobile producers build obsolescence into their products, which may or may not be true, may be in the consumer's interest if it is true!

D. Some Special Cases

Before moving to the producer's problem, let us examine some special cases in order to clarify and expand the foregoing analysis and implications thereof. Suppose, in the first situation, that consumers expect the price of new durables to be unchanged from t onward at a level of $p_d(t)$ and also expect the operating cost to remain constant at a level of $G(t)$. From (6-11b), the price of a unit of service[6] derived from the durable good then reduces to:

(6-13) $$\pi(t) = \frac{r[p_d(t) + G(t)]}{1-e^{-rT}}$$

In this simplified form, the implicit rental price is equal to the interest rate multiplied by the present value of the cost of maintaining and using a unit of the durable good in perpetuity.

Furthermore, from (6-11c), the implicit price of a unit of durability per unit of net investment is:

(6-14) $$\gamma(t) = \left[\frac{p_d(t)'}{1-e^{-rT}} - \frac{(p_d(t) + G(t))}{rT^2}\right]$$

where $\frac{\partial p_d(t)}{\partial T}$ is expressed for notational convenience by $p_d(t)'$. Substituting (6-13) into (6-14), we have:

(6-15) $$\gamma(t) = \left[\frac{p_d(t)'}{1-e^{-rT}} - \frac{\pi(t)(1-e^{-rT})}{r^2\ T^2}\right]$$

Equation (6-15) states that the implicit price of a unit of durability is equal to the discounted value of the cost of an additional unit of durability less the discounted value of the postponed savings from purchasing a more durable good today. Clearly, as the cost of additional durability ($p_d(t)'$) increases, $\gamma(t)$ increases and the demand for durability decreases. On the other hand, an increase in the implicit rental price of the service, caused for example by an increase in the price of the durable good, results in a future savings from purchasing a good of greater durability today. Thus, as $\pi(t)$ increases, $\gamma(t)$ is reduced and the demand for durability increases. Alternatively, an increase in efficiency reduces $G(t)$ and implies a greater value for $\gamma(t)$ and, hence, a reduction in the demand for durability.

Suppose, on the other hand, we assume the consumer expects all prices as well as the operating efficiency of the good to rise exponentially. For simplicity the operating cost function can be represented by:

$$G(t) = \frac{p_v(t)}{E(t)} \tag{6-16}$$

That is, the operating cost per mile driven in an automobile is the price per gallon of gasoline divided by the miles per gallon.

Let the price of the durable good rise exponentially at a rate of Θ_d per period, the price of the variable input rise at Θ_v, and the efficiency rise at a rate of Θ_e per period. It follows that the implicit price of a unit of service is then:

$$\pi(t) = \frac{p_d(t)(r-\Theta_d)}{1-e^{-(r-\Theta_d)T}} + \frac{p_v(t)}{E(t)}\left[\frac{r+\Theta_e-\Theta_v}{1-e^{-(r+\Theta_e-\Theta_v)}}\right] \tag{6-17}$$

It is easily seen from (6-17) that an increase in the rate of interest, r, increases the service price, as does an increase in the rate of change in efficiency, Θ_e. Likewise, an increase in the rate of change in the price of the durable good and/or the price of the variable input reduces the service price in period t.

The price of durability per unit of net investment can, furthermore, be expressed as:

$$\gamma(t) = \left[\frac{p_d(t)'}{1-e^{-(r-\Theta_d)T}} - \frac{p_d(t)}{(r-\Theta_d)T^2} - \frac{p_v(t)}{E(t)}\left[\frac{1}{(r+\Theta_e-\Theta_v)T^2}\right]\right] \tag{6-18}$$

Equation (6-18) states that the effective price of durability is the discounted value of the increase in price of the good due to its added durability less the present values of the postponed savings in purchasing the durable good in the future and the associated future operating costs.

As was suggested earlier, an increase in the expected rate at which operating efficiency is increasing over time relative to the increase in the expected rate of the variable input price will clearly increase the effective price of durability to consumers and result in a reduction in demand for durability. Moreover, an increase in the rate at which the price of the durable good is expected to rise reduces the price of durability and, hence, increases the demand for this attribute.

III. The Producers' Problem of Supplying Durability

The consumer's demand for durability is but one side of the problem. In order for this demand to be satisfied, producers must build the product with the required level of the characteristic. That is, the consumer's optimality conditions become constraints on the firm optimization procedure so that the markets for the goods ultimately clear, i.e. supply equals demand.

A. Assumptions

Throughout the analysis of the producer's problem we maintain the cost assumptions of Swan (1970), Levhari and Srinivasan (1969) and Parks (1974). Specifically, we assume the long-run average (= marginal) cost of producing a unit of the asset depends on its built-in durability and the efficiency chosen by the producer. Moreover, we assume a large number of potential producing units each with identical costs, either operating as independent competitors or operated by a monopolist with no effect on costs. Finally, we assume that producers have no existing stock of goods and they plan to sell the goods produced at the same price over time.

B. Model

Let the per unit cost of producing the asset be represented by C, where

(6-19) $$C = C(E,T)$$

That is, cost is a function of built-in efficiency and durability alone. Assuming this cost function is separable,

(6-20) $$C = H(E)D(T) ,$$

where $H(E)$ is the cost of producing one unit of the asset with an operating efficiency of E and $D(T)$ is the cost associated with a durability of T periods.

The present value of the net receipts to the firm can then be given by

(6-21) $$V = [Qp_d - QH(E)D(T)] \sum_{n=0}^{\infty} e^{-rnT}$$

$$= \frac{Q[p_d - H(E)D(T)]}{1 - e^{-rT}}$$

where Q represents the level of sales of the asset needed to maintain the service flow at level Q.

Because we are assuming a constant price for the durable asset of p_d, we can solve for p_d in the expression for the service price in equation (6-12), i.e.

$$p_d = \frac{\pi(1 - e^{-rT})}{r} - G \tag{6-22}$$

Substituting (6-22) into the expression for the present value of the net receipts in (6-21), we have

$$V = \frac{Q\pi}{r} - \frac{Q(G + HD)}{1 - e^{-rT}} \tag{6-23}$$

Finally, let $\pi = g(Q,T)$ represent the inverse of the demand relation for services of the durable good. Substituting into (6-23),

$$V = \frac{Qg(Q,T)}{r} - \frac{Q(G + HD)}{1 - e^{-rT}} \tag{6-24}$$

The monopolist will chosse the combination of Q and T that maximizes V. The conditions for a maximum are:

$$\frac{\partial V}{\partial Q} = \frac{Qg_Q(Q,T) + g(Q,T)}{r} - \frac{(G + HD)}{1-e^{-rT}} = 0 \tag{6-25a}$$

(6-25b) and

$$\frac{\partial V}{\partial T} = \frac{Qg_T(Q,T)}{r} - \left[\frac{HD'(T)(1-e^{-rT})-(G+HD)re^{-rT}}{(1 - e^{rT})^2}\right] = 0$$

Equation (6-25a) is the familiar discounted marginal revenue equals discounted marginal cost result. Resubstituting the expression $g(Q,T)$ into (6-12), equation (6-25a) takes on the more intuitively appealing form:

$$\frac{(Q \frac{\partial p_d}{\partial Q} + p_d) - HD}{1 - e^{-rT}} = 0 \quad , \quad \text{or}$$

(6-26) $$Q \frac{\partial p_d}{\partial Q} + p_d = HD$$

Equation (6-26) states that in each period, the firm equates the marginal revenue to the marginal cost.

Equation (6-25b) is the condition for determining the firm's optimal level of durability to build into its product. Again, substituting the expression for $g(Q,T)$ into (6-25b), we have

(6-27) $$p_d' - \frac{r\, p_d\, e^{-rT}}{1 - e^{-rT}} = HD' - \frac{r\, HDe^{-rT}}{1 - e^{-rT}}$$

The first term on the L.H.S. of (6-27) is the increase in the price of the durable good caused by an increase in durability. The second term is the present value of the lost future revenues due to postponed purchases of the good. The first term on the R.H.S. is the marginal cost of producing a more durable good while the second term is the discounted cost savings from postponed production of the durable good in the future.

Rearranging terms, (6-27) can be expressed more simply as:

(6-28) $$p_d' - HD' = \frac{r}{e^{rT} - 1} (p_d - HD)$$

Clearly, the durability supplied by the monopolist will differ from that supplied by the competitive firm since p_d' (which is a function of Q) is incorporated within the monopolist's optimal choice of durability. In particular, it can be easily shown that the monopolist will supply less durability than its competitive counterpart. To see this, substitute the competitive pricing solution into (6-28), yielding:

$$p_d' = HD' \tag{6-29}$$

That is, the competitive firm will choose a level of durability such that the incremental benefit (p_d') is exactly equal to its incremental cost (HD'). Let the optimal level of durability for the competitive firm be Tc.

The monopolist, on the other hand, will choose the durability of its product by substituting (6-26) into (6-28), or

$$p_d' = HD' - Q \frac{\partial p_d}{\partial Q} \left[\frac{r}{e^{rT} - 1} \right] \tag{6-30}$$

Equation (6-30) says that the monopolist will incorporate a level of durability (Tm), into its product so as to equate the incremental benefit from an additional unit of durability to something greater than the incremental cost of the increased durability. As long as the incremental benefit decreases with added durability as one would reasonably expect to be the case, equation (6-30) is satisfied at a lower level of durability than is equation (6-29). Alternatively, if equation (6-30) is evaluated at Tc, the L.H.S. is less than the R.H.S. Hence, it is clear that Tm < Tc.

IV. Product Durability as an Entry Barrier

Throughout the preceding analysis, we have assumed, like our predecessors, that the monopoly situation exists due to some entry prohibiting phenomenon, either innocently or strategically applied by the firm, but in either case, independent of the firm's choice of product durability. Interestingly, however, is that the firm's choice of product durability can be the barrier that precludes entry into the industry and thus allows the firm to operate as a monopolist. Before discussing the particular features of the product durability decision in discouraging entry, we shall first discuss the problem of entry barriers in more general terms.

Steven Salop (1979) has presented an excellent overview of the entry barrier literature which is worthwhile to summarize here. Salop notes that there are two classes of entry barriers that may be distinguished. An innocent entry barrier is unintentionally erected as a side effect of innocent profit maximization. In contrast, a strategic entry barrier is purposely erected to reduce the possibility of entry.

Moreover, two types of innocent barriers may be differentiated. A post-entry absolute advantage has the property that, if entry did occur, the established firm would be at a profit advantage over the entrant. Examples of a post-entry absolute advantage include superior technology, patents, and lower input prices. On the other hand, a pre-entry asymmetry advantage arises from the fundamental pre-entry asymmetry between the established firm and the potential entrant. Before the entrant makes his entry decision, the established firm has already committed resources. This prior existence gives first move advantages.

Consider, for example, the innocent barrier due to scale economies. The potential entrant should ignore the pre-entry price and profit levels of the established firm and should attempt, instead, to infer the post-entry equilibrium price and profit levels. If the entrant's expected profits are negative, he is deterred. Even a more efficient entrant may be deterred by an established firm that has sunk sufficient costs to make his own exit uneconomical, and hence, entry is mutually harmful.

The fundamental asymmetry in the post-entry game provides the foundation for the theory of strategic barriers against equally efficient potential entrants. By making binding commitments and communicating them during the pre-entry period, a strategically minded established firm is able to exploit its leadership role. If the commitments imply negative profits to the entrant in the post-entry game, then entry will be successfully deterred.

Let us now leave the general entry deterrence problem and focus on the specific deterrence instrument - product durability. In the absence of entry, suppose an established firm (monopolist) can earn positive present discounted value of profits V_o. Given some assured and agreed upon rule governing post-entry interaction between the established firm(s) and entrants, the established firm and equally efficient large scale entrant would each earn $V_1 < V_o$. If $V_1 > 0$, entry will occur.

Alternatively, suppose there is a minimum level of durability associated with the particular good produced by firms in this industry. Levels of durability in excess of this minimum are possible to achieve by the manufacturer and are generally regarded positively by consumers, _ceteris paribus_. Durability levels below the minimum are assumed unobtainable for institutional reasons, e.g., government quality standards, threat of legal action by consumers, etc. For simplicity, we assume the minimum level of durability has zero cost. Suppose further that the established firm has the opportunity to select a pre-entry expenditure level D(T), for any T above the minimum, that the entrant must exactly match in order to survive, where D(T) is the cost of producing a good with a durability of T periods. The greater is the level of durability (T) chosen by the established firm, the greater is the cost, D(T), faced by the entrant. The outcomes can be summarized as follows:

ESTABLISHED FIRM

ENTRANT	Minimum Product Durability	Spends D(T) on Durability
Enters and matches established firm	V_1, V_1	V_1-D(T), V_1-D(T)
No entry	0,V_0	0,V_0-D(T)

where the entrant's outcome is given first in each case.

If the established firm employs the minimum level of product durability, for example T_m as determined in the previous section, and the potential entrant enters and also employs T_m in his product, both firms will earn V_1 which is less than the V_0 that could be earned by the unobstructed monopolist. If, on the other hand, the established firm only employs a durability level of T_m and the potential entrant did not enter, the established firm would earn V_0.

Suppose now that the established firm employs a level of durability $T_e > T_m$ and the potential entrant competes with a product also of durability T_e. Profits to both firms will then be V_1-$D(T_e)$. If, however, the potential entrant is deterred by the established firm's durability choice of T_e, at a cost of $D(T_e)$, the established firm will earn V_o-$D(T_e)$.

It is clear then that by producing a good with a level of durability, T_e, such that $D(T_e) > V_1$, the entrant is deterred by the prospect of non-positive profits and the established firm earns V_o-$D(T_e)$. Thus, at the minimum deterrence level, $D(Te) = V_1$, deterrence is profitable as long as $V_o - D(Te) \geq V_1$, or alternatively $V_o \geq 2V_1$.

The established firm, facing the threat of entry, has an incentive to produce a more durable product than would the same firm enjoying a non-threatened monopoly position due to some other entry barrier, innocent or strategic. Thus, two opposing forces determine the optimal level of product durability. On the one hand, the monopolist would choose to produce a good of relatively low durability and in doing so would enable consumers to readily adapt to more energy efficient technologies as they become available. On the other hand, it appears that increased product durability can be an effective entry deterrent in allowing the established firm to maintain its monopoly position. It would appear that the existence or absence of alternative entry barriers will determine the need for the firm to exercise its ability to limit entry through its choice of extended product durability. In the automobile industry, for example, entry barriers may take the form of scale economies, economies of scope, and advertising. It is likely that these instruments are sufficient to deter entry and that extended durability would only have a negligible impact in this particular industry. Hence, one might reasonably accept the automobile industry as exhibiting significant market power due to any number of deterrence instruments available to established firms other than the choice of product durability. As such, it is also reasonable to conclude that industry members produce products of a durability inversely related to the degree of market power enjoyed by industry members. In so much as this low level of durability provides greater flexibility for consumers to readily adopt a more energy efficient technology as it becomes available, the welfare costs attributable to the monopolist are at least partially offset by the ability of consumers of the monopolist to utilize less energy than purchasers of the competitively supplied more durable good.

CHAPTER SEVEN:

SUMMARY, IMPLICATIONS AND OTHER APPLICATIONS

I. Summary

The primary objective of this study has been to identify the characteristics that influence the energy efficiency of automobiles and determine how the value of these characteristics to consumers has changed in response to changing gasoline prices. The results derived in this study indicate a strong impact of energy prices on consumers' decisions to purchase more (or less) energy efficient automobiles and, hence, gasoline through the composition of characteristics embodied in the automobiles purchased.

To satisfy the objectives of the study, Chapter 2 presented the concept of a good utilized throughout the project. That is, a good was defined as a bundle of characteristics and consumers purchase goods for the particular characteristics embodied within the goods. A general relationship between the price of a good and the amount of each characteristic within the good was then developed in Chapter 3. This relationship is known as an hedonic pricing model and the coefficients of the characteristics are referred to as hedonic, or implicit, prices of the characteristics. That is, the hedonic price of a characteristic is the implicit price paid for that characteristic when the good is purchased. In so far as prices paid by consumers generally reflect the value of the good purchased, the hedonic prices of the characteristics similarly reflect their value to consumers.

Chapter 4 concentrated on the specific good that was to be analyzed in this study - automobiles. In particular, an examination was made of the relevant characteristics that effect the energy efficiency of automobiles. It was determined that for each of the years 1977 through 1980, in which Canadian automobile efficiency data were available, vehicle weight and cubic inch displacement consistently explained over 80 percent of the variation in energy efficiencies across automobiles. Over the years examined, however, there appears to be a decline in the effect of weight on energy efficiency likely due to the impact of technology improvements in producing lighter vehicles.

Chapter 5 was concerned with estimation of the hedonic pricing model. Among the more interesting results, it was observed that the interior volume of vehicles was only considered important (i.e., had a statistically significant hedonic price) by consumers in 1980, following major downsizings by the industry. Furthermore, when sales were weighted by market share and the model was estimated on standard North American vehicles alone, weight and number of cylinders explained about 90 percent of the variation in automobile prices across models in each test year. The relationship appears linear rather than non-linear as well. Moreover, irrespective of the particular explanatory variables included, the weighted model always performed better than the unweighted model with the same independent variables.

When the original sample was supplemented by non-standard vehicles, the bias introduced by our assumption that used car sales reflect original sales of new models was more serious due to the variation in durability across vehicles in the appended sample. Even though the results indicated a significant positive amount that consumers are willing to pay for purchasing a non-standard car, perhaps due to a difference in quality, the bias introduced with this sample resulted in consistently lower R^2's.

When the hedonic prices of weight and number of cylinders, for one-year old vehicles, were compared to real domestic gasoline and oil prices, the relationship was as expected. An increase in energy prices decreased both the value attached to weight and additional cylinders by consumers. To confirm the relationship between energy prices and energy consuming automobile characteristics, we also examined the Black Book values for air-conditioning, automatic transmission, and additional cylinders for two periods - December 1978-79 and December 1979-80. During the first period, there was a decrease in real gasoline prices while the second period was one in which real gasoline prices showed a dramatic increase. Generally, the change in values suggested by the Black Book for these three characteristics were consistent with the change in energy prices.

The purpose of Chapter 6 was to develop a model which could be used to examine both the demand and supply of durability in an uncertain technological environment. The motivation for this discussion is that for many energy intensive capital goods, like automobiles, furnaces, etc., the potential for future technological change may imply that such goods be produced at a lower durability so that consumers have the flexibility to purchase the more energy efficient technology as it comes on stream. The results of the analysis suggest that the greater is the market power of firms in the industry, the lower is the level of durability supplied which may be in the consumers' interests. At the same time, however, product durability is a potential barrier to entry so that firms may have an incentive to produce goods of a longer life in order to discourage entry into the industry. In the automobile industry, other barriers aside from product durability are likely responsible for the existing structure of the industry so that the offered durability of automobiles is most influenced by the monopoly power of the industry and is, therefore, less than would be offered by firms in a competitive industry.

II. Implications for Policy

A number of policy implications arise from this study. First, the claim has often been voiced that North American automobile manufacturers build a product of two low a durability, or they build obsolescence into their products. The analysis conducted in this study suggests that these firms do have an incentive to produce automobiles of a lower level of durability than would firms in a competitive industry. At the same time, however, offering products of lower durability may be in the interests of consumers if industry members are seriously engaged in research and development directed toward improved vehicle energy efficiency. The ability of firms in this industry to withhold adoption and utilization of such an invention for reasons relating to self-profitability undermine the positive effects associated with the lower durability product offered by industry members. To encourage the future technological advances required for any benefit to be realized from consumers purchasing automobiles today of lower durability, it is important to have research and development conducted independently of the industry - perhaps even supported or directly undertaken by government.

Another implication of the foregoing analysis related to the tradeoff observed between vehicle weight and energy efficiency. Automobiles have become lighter since 1977 as witnessed by the average curb weight adjusted for market share of the sample used in this study of 3292 pounds. On the other hand, in 1980, the adjusted average weight of the sample was 2920 pounds, a decrease of 11 percent. Associated with this reduction in weight has been an increase in energy efficiency, or savings. However, also associated with the heavier vehicles are two additional costs. First, the lighter weight automobiles have incurred greater damages in even minor accidents than have the heavier vehicles which has lead to the possibility that insurance companies may increase disproportionately collision rates for lighter, smaller cars. This extra cost burden when deducted from the value of the energy savings may significantly reduce the benefits of purchasing lighter cars and, hence, will effect the demand for these vehicles. A second cost of owning a light, energy efficient car is the increase in likelihood of personal damage which may again be reflected in higher insurance rates, or an individual's own risk aversion. In either case, this cost must also be netted against the energy savings and will to some extent influence the demand for lighter cars. Of course, higher energy prices act to somewhat offset the safety factor so that this potentially harmful effect of higher energy prices must be "weighed" against the more publicized energy savings benefits.

Throughout this study we have referred to the energy savings associated with higher energy prices over the period 1977-80. Actual determination of the savings, however, is a multiple-step procedure requiring more years of data than the four years available in this study. For each year, the first step requires estimation of the hedonic price associated with vehicle weight as we have done for the years 1977-80. The next step is to regress real gasoline prices against the yearly hedonic price of weight. Then, the demand for vehicle weight is estimated using the time series of average vehicle weights, hedonic prices, and income. One problem that arises here is errors in variables since the price observations are stochastic, having been estimated by ordinary least squares. Consequently, the estimated coefficients are biased and inconsistent. This problem is overcome through the use of an instrumental variables approach.

The fourth step is to estimate, as we did in Chapter 4, the relationship between energy efficiency and vehicle weight. Finally, since gasoline consumption is a function of both energy efficiency and miles driven, for an average number of miles, say 12000 miles per year, the effect of an increase in gasoline prices can be traced through to the effect upon gasoline consumption. Moreover, since we know the cars included in the yearly samples comprise about 60 percent of all automobile sales in Canada, the aggregate effect of an increase in gasoline prices on gasoline consumption can be estimated.

The advantage of estimating gasoline consumption in this manner is that it is possible to isolate the particular characteristics that have the greatest impact for reducing energy consumption within the context of the present technology. Moreover, this procedure identifies the necessity to consider the tradeoff between certain characteristics that are most effective in reducing energy consumption and other characteristics desired by consumers.

III. Application to Residential Furnaces

The analysis applied to automobiles in this study has direct application to residential furnaces. Furnace characteristic data are, however, not available in centrally located form so that manufacturers would have to be individually contacted for the information relating to their specific products.

As a starting point in understanding the problems with relating furnace efficiency to the physical characteristics of the furnace and then estimating the hedonic prices of the relevant characteristics, a partial bibliography of related work is presented in the Appendix to this chapter.

While the required data for automobiles appears easier to collect than that for furnaces, a greater number of years of data is available for the latter. Therefore, the estimation procedure can likely be carried to its final step for furnaces and the aggregate energy reduction attributed to higher energy prices estimated.

Appendix

Partial Bibliography for Determining the Hedonic Prices of Furnace Characteristics

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FOOTNOTES

Chapter 2

1. See, for example, Johnson (1958) among others.
2. Ironmonger (1972) developed a theory quite similar to Lancaster's. In his theory, Ironmonger views characteristics as want satisfiers and consumers are believed to possess a priority ranking of wants, trying to satisfy wants in order of priority.
3. Lancaster's definition of goods is such that different brands classify as different goods.

Chapter 3

1. Each characteristic, in turn, is assumed to exhibit positive marginal utility.

Chapter 4

1. Initially we followed previous studies and used the Canadian Red Book (published by Maclean-Hunter Ltd.) for car prices. Conversations with used car dealers, however, suggested strongly that the Red Book prices were not representative of actual transactions prices, but instead, most dealers used the Black Book.
2. Evidence of downsizing can be seen in the mean and standard deviation of the curbweights in each sample year. For 1977, the average weight was 3101 pounds with a standard deviation of 577.4 pounds. In 1978, the mean weight was 3046 pounds with a standard deviation of 635.3 pounds. By 1979, the mean weight dropped to 2879 pounds and the standard weight deviation was 528.5 pounds. Finally, in 1980, the average weight was 2937 pounds, but the deviation was only 510.9 pounds.

Chapter 5

1. See, for example, Dewees (1974) and Griliches (1961), among others.
2. Width was measured as the average of the front shoulder room and rear shoulder room while the length was measured as the sum of the front leg room and the rear seat room. Height was calculated as the average of the front head room and the rear head room plus 41 inches so as to account for the average 5 foot 9 inch individual weighing 150 pounds sitting in the seat.
3. The Federal Air Conditioning Excise Tax ($100 per automobile air condition) was in force as of May 26, 1976 so it does not effect the results.

Chapter 6

1. Authors have in fact experimented with depreciation patterns. See, for example, Parks (1966) who uses a constant evaporation depreciation assumption and Sieper and Swan (1973) who use a general monotonic depreciation pattern.
2. While it is recognized that the consumer does not actually have an infinite life, this approximation for computational ease results in only minor distortions. To see this, it need only be realized that the present worth of $50,000 to be received 50 years from now has a value of only $425 today assuming a discount rate of 10 per cent.
3. Refer to Dixit (1976) for a description of calculus of variations optimization procedure.
4. Recall that if the full prices of durables reflect efficiency and prices of the respective variable inputs, sale of the good in an efficiently operating second-hand market will sufficiently discount the value of of the good so as to penalize the consumer for making an incorrect decision with respect to his durability choice.

5. Refer to Schalensee (1979) for a review.

6. The service price is defined as the implicit rental price of the service, i.e. the price one would pay if they rented the good.

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