POLICY-ORIENTED MODELING OF NEW AUTOMOBILE SALES AND FUEL CONSUMPTION

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Interactive computer models are described that project changes in the use and ownership of automobiles. An automobile ownership model projects changes in total automobile ownership, a scrappage model estimates the number of automobiles in each age class that will be scrapped, and a new automobile market segmentation model estimates changes in the mix of new automobiles sold in each of three size classes. The models age the automobile population year by year and forecast the number of new automobiles that will be sold and added to the inventory of automobiles in use. Included within the models are a number of economic variables relating to the costs of ownership and operation, each of which may be affected by public policy and may be treated as policy instruments for, say, reducing automotive fuel consumption. The models have been used for a variety of policy impact assessments and are useful for the evaluation of alternative policy choices affecting the use and ownership of automobiles.

Rational policy choices dealing with automotive fuel consumption and specifically with measures to reduce such fuel consumption require, among other things, an ability to quantify the effects of different government actions on the direct objective (i.e., the reduction of fuel consumption) and on a variety of other important concerns that ultimately determine whether a given action is more or less desirable than another. Clearly, the need exists for the application of a forecasting capability that captures the multiplicity of interacting forces at work and that reflects in a realistic way the effects of various policy actions that might be proposed. The modeling effort to be reviewed here is the result of work that was begun in 1971 and carried on until mid-1974 to refine quantitative methods for the analysis of the complex of factors impacting on and impacted by the use of automobiles. The objective was to attempt to provide the kind of analyses that could aid in the development of corporate policy.

Three sets of factors are at work that jointly determine demand for automobiles and derivatively the demand for gasoline; these factors may be characterized as market forces, government forces, and industry responses. They have a large number of complex interactions and, of course, many elements of uncertainty. The demand for automotive fuel is a direct result of (a) changes of the number of vehicles in use, (b) changes in the use of these vehicles, and (c) changes in the fuel consumption characteristics of these vehicles. Each of these factors, in turn, is affected by a number of variables and the dynamic interactions related to them. Different government policies directed toward reducing automotive fuel consumption can affect each of these factors in markedly different ways and result in widely differing effects on new automobile sales.

OVERVIEW OF MODEL STRUCTURE

The basic argument of the model is deceptively simple:

SALES = ΔUIO + SCRAPPAGE

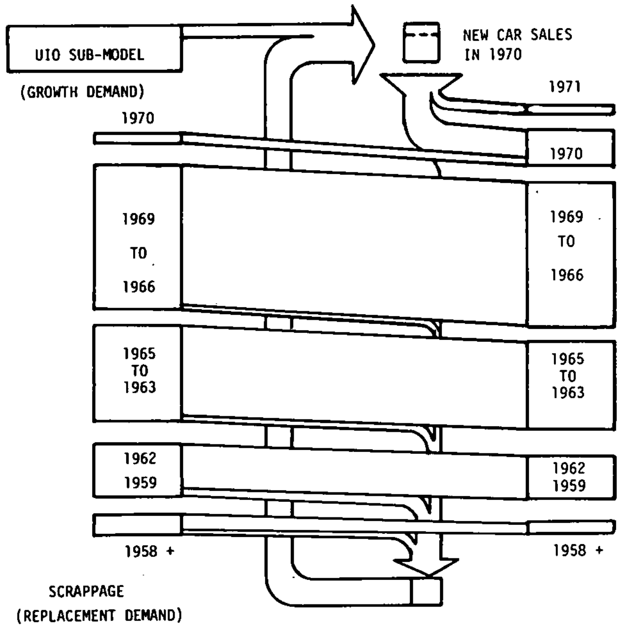
New automobile sales is the sum of the change in the number of units in operation (the growth component of the market) and the number of units scrapped (the replacement component of the market). It is important to recognize that the replacement component represents an increasing percentage of total new automobile sales as total automobile ownership approaches saturation. By the early 1980s, the scrappage component is projected to account for 80 percent of sales. It is of particular importance, therefore, to simulate the interplay of factors that influence scrappage.

Figure 1 shows a schematic representation of the overall model structure; 1970 is used, arbitrarily, as the base year. For convenience in presentation, automobile model years are aggregated; in the computer model, 17 model-year classes are represented, with 17-year-old and all older automobiles included in the seventeenth class. The models were programmed in TIME-SHARED BASIC and run on an HP-2000.

In general terms, the model starts, for a selected year, with input of the distribution of the total number of automobiles in use by the 17 model-year classes, including a number of attributes of the automobiles in each model-year class, e.g., size and weight class and average specific fuel consumption and a set of parameters

*The work described was performed while the author was with the Transportation Research and Planning Office of the Ford Motor Company.

Figure 1. Overview of model structure.



that determine the functional relations among model variables. The model then ages the automobile population, year by year, throughout a forecast period, forecasting for each year the number of automobiles of each model year and size class that will be scrapped and the number of new automobiles that will be sold and added to the inventory by size class and average specific fuel consumption. Included within the model are a number of usage parameters such that, in addition to a number of measures relating to the changes in automobile population, scrappage, and new automobile sales, the model provides outputs such as vehicle-kilometers, either for the total automobile population or any subclass, fuel consumption, either total or for any subclass, and the like.

The three principal submodels may be briefly characterized as follows.

1. The automobile ownership submodel projects total automobile ownership and change in units in operation (UIO). A number of ownership models have been developed and tested (1). One of these involves the use of logistic functions to represent trends in one-automobile, two-automobile, and three-or-more-automobile households to project family ownership. The commercial-public sector ownership is treated separately.

2. The automobile use and scrappage submodel estimates the probabilities of scrappage for each age and size class of automobile (and accumulates scrapped units and updates the age class) in relation to (a) the depreciated average value, which in turn can be affected by changes in new automobile prices or performance characteristics or both; (b) the probability that an automobile will suffer accident damage or incur costs to remain in operations, which in turn is affected both by changes in usage as a function or gasoline prices (gasoline supply constraints or rationing) and by a normalized involvement rate, which may be affected by vehicle maintenance, driving speed, and other factors; and (c) a repair cost distribution, which again can be a function of other variables, e.g., labor costs and product characteristics.

3. The new automobile sales and market segmentation submodel then (a) projects new automobile sales as the sum of the change in total automobiles in operation plus number of automobiles scrapped and (b) estimates segmentation by operation and ownership and changes in a set of switching matrices. The switching matrices represent the probability that the owner of one size class automobile will purchase an automobile in the same size class or in another size class. Data on specific fuel economy are input exogenously in relation to anticipated standards or expected industry performance or both.

An example of the variety of ways in which a change in a single input parameter can affect the behavior and output of the model is the way a change in the price of gasoline operates within the model. Assume that, either on the basis of an economic forecast or to test gasoline tax policies, a schedule of average gasoline price changes during the forecast period is developed and that this change represents an increase over historical trends. This forecast is translated into either an index rate change, if it can be represented as such, or a set of year-by-year index values. Each of the submodels is affected. The automobile use and scrappage submodel is affected through a modification of the use distribution on the basis of an estimated price elasticity. In the new automobile sales and market segmentation submodel, the switching matrices are modified in terms of a weighted deviation from the historical trend, which is treated as a time-scale change, and an adjustment (albeit small) is made to total new automobile sales on the basis of an estimated elasticity represented by a gasoline price-weighted change in the cost of ownership. The net effects on the output are quantified estimates of the contribution of the gasoline price increases to the reduction in total vehicle-kilometers, the reduction in gasoline demand, the reduction in scrappage, the shift in market mix toward smaller, more fuel economical automobiles, and the reduction in new automobile sales. Appropriate other adjustments are incorporated in the models to capture the effects of a gasoline shortage, e.g., by apportioning the shortfall from the unconstrained demand and adjusting usage. In such fashion, therefore, the model provides a tool for the analysis of the interplay of market forces or the impacts of policy choices that might be implemented or both. The above represents a broad-brush picture of the general structure and workings of the model.

Before proceeding to a more detailed description of the content of these models, I should note that what happens in the new automobile market is directly influenced by conditions affecting the total population of people who own and use automobiles and not simply by the behavior of new automobile buyers. This is particularly true in view of the magnitude of the scrappage-replacement market. Policies directed toward new automobiles or representing cost penalties on new automobiles can profoundly affect decisions of automobile owners about whether to buy a new automobile versus a used automobile versus keeping a present automobile a little longer. Similarly, of course, policies that affect new automobile prices can have a profound effect on the decision of what type of new automobile to buy.

AUTOMOBILE OWNERSHIP MODEL

A series of models of automobile ownership were developed, including separate models based on

1. Trends implying saturation in the number of automobiles per licensed driver;

2. Trends in household automobile ownership, including one-automobile, two-automobile, and three-or-more automobile households (each of these components

is represented by a three-parameter logistic function of the form

$$F_i = k_i/[1 + \exp(A_i - B_i t)] \qquad (1)$$

where

i = 1, 2, 3,
k_i = saturation values, $0 < k_i < 1$,
A_i and B_i = parameters for ownership class i, and
t = year);

3. Trends in family automobile ownership rates in relation to type of housing, i.e., single-family detached versus multiunit housing; and
4. Trends in family automobile ownership rates in relation to occupancy status, i.e., owner versus renter-occupied housing.

For all but the first model, total automobile ownership is the sum of family automobile ownership and commercial-public sector automobile ownership. The commercial-public component is now treated as a linear function. The above submodels were developed to compare different large-scale changes or trends affecting total automobile ownership. Highly consistent results were obtained. Consequently, only one is implemented in the present set. The projected growth in total UIO and the implied ΔUIO are given in Table 1.

CAR USE AND SCRAPPAGE MODEL

The scrappage modeling problem is one of identifying and representing the processes that generate automobile mortality, i.e., of estimating the probability that, in any particular forecast year, any given model-year automobile will be scrapped. The basic argument of the model is relatively simple; its working out involves a number of complex interactions and a number of difficult data problems. The basic argument is as follows:

1. Normal aging and wear are represented by the decrease in average value of an automobile over time, i.e., a depreciation rate;
2. Automobiles, during their lifetimes, are also subject to various shocks and insults, e.g., traffic accidents, fire, theft, vandalism, and major breakdown—events that result in a cost that must be incurred to return the automobile to an operational status; and
3. When such costs exceed the depreciated value of the automobile, it is scrapped, i.e., not reregistered.

The calculation of specific mortality rates, thus, has three major components. Each major component has two elements: a model-year element i, which is a distribution by age of automobile; and a calendar-year element j, which represents a rate of change over time. Each major component, furthermore, can be the product or result of several subcomponents or contributing factors. The major components are average value distribution, damage rate distribution, and repair cost distribution. Each of these is discussed in turn, and then they are combined for the computation of scrappage probabilities.

Average Value Distribution

The average value, $W_{i,j}$, of an i-year-old automobile j-years from a base-year value of W_o is represented by an equation of the following form:

$$W_{i,j} = W_o * A^i * B^j * F(i) \qquad (2)$$

where A (the depreciation rate) is estimated on the basis of historic data on used automobile values, B is what might be called an inflation factor and is estimated on the basis of the historic change in average new automobile prices, and F(i) is a correction factor to account for the circumstance that the values of automobiles older than 9 years depart from the exponential decay, F(i) = 1 for i = 0, 1, 2, . . . , 8, and F(i) > 1 for i = 9, 10, . . . , 17.

The $W_{i,j}$ of equation 2 represents the normal (historical) relation between new automobile prices and used automobile values. Figure 2 shows the distribution for January 1970. The value of A has been relatively constant during the last 2 decades. If significant departures from the normal relation can be expected, e.g., a relative increase in the valuation of older automobiles associated with the degraded performance and fuel economy of emission-controlled automobiles, then suitable modifications of equation 2 can be introduced exogenously at the appropriate time period in a simulation run. Similarly, variations in scrap pieces can be used as a floor for the value distribution.

Damage Rate Distribution

The damage rate, $R_{i,j}$, for an i-year-old car j-years from a base-year rate of R_o is given by the following:

$$R_{i,j} = R_o * \exp[(A + B) * (i - 1)] * C^j \qquad (3)$$

where A is a usage parameter based on the average kilometers driven per year by age of automobile (the value of A is a negative, as shown in Figure 3), B is a normalized accident involvement rate by age of automobile and is positive (Figure 4), and C is the rate of change of the base rate over time.

Based on historical data, (A + B) is slightly negative. It will be observed, however, that factors that affect either A (usage) or B (involvement rate) will have a significant effect on $R_{i,j}$ and hence on scrappage probabilities. For example, an increase in gasoline prices will reduce usage and thereby reduce $R_{i,j}$. The model currently incorporates a gasoline price elasticity, treated at a cost of operation-weighed use factor, which modifies the A-parameter in the exponential part of $R_{i,j}$.

Repair Cost Distribution

The probability that the repair cost, $Q_{x,j}$, will be less than X-dollars in j-years from the base year is given by a Weibull distribution as follows:

$$Q_{x,j} = 1 - \exp - [X/(T_o * A^j)]^B \qquad (4)$$

where

T_o = base-year Weibull parameter related to the average cost to repair,
A = repair cost growth rate, and
B = Weibull slope parameter.

Again, it will seem that factors that may change the repair cost distribution will affect scrappage. Figure 5 shows the repair cost distribution for 1970. Equation 4 has been estimated on the basis of extensive repair cost data collected and analyzed by the Car Research Group at Ford Motor Company.

Scrappage Probability

When the above relations are combined, the scrappage probability ($P_{i,j}$) that an i-year-old automobile will be

Table 1. Growth in automobile ownership.

Year	January UIO	ΔUIO
1974	83 487 000	2 457 000
1975	88 404 000	2 460 000
1976	90 864 000	2 457 000
1977	93 321 000	2 451 000
1978	95 772 000	2 445 000
1979	98 217 000	2 438 000
1980	100 655 000	2 430 000
1981	103 085 000	2 422 000
1982	105 507 000	2 417 000
1983	107 924 000	2 413 000
1984	110 337 000	2 409 000
1985	112 746 000	2 409 000

Figure 2. Average value of automobile by model year, January 1970.

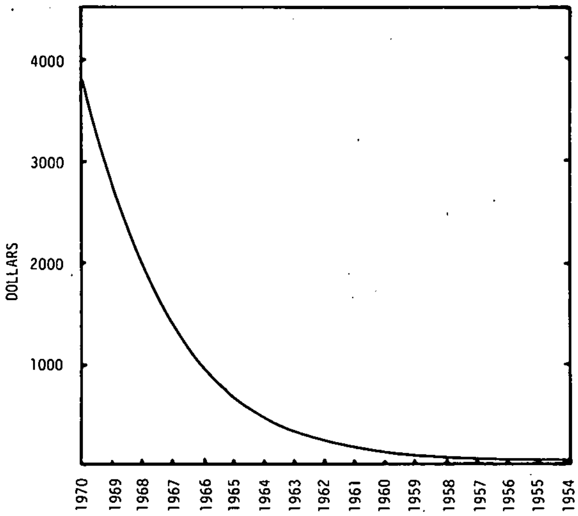


Figure 3. Distribution of usage by age of automobile.

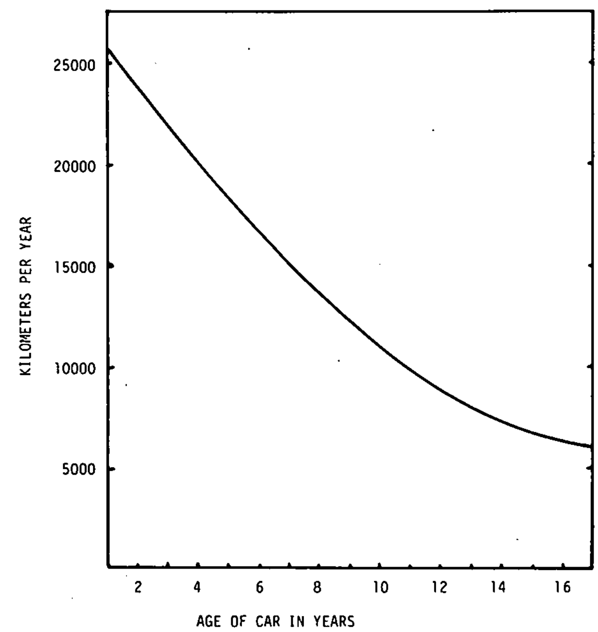
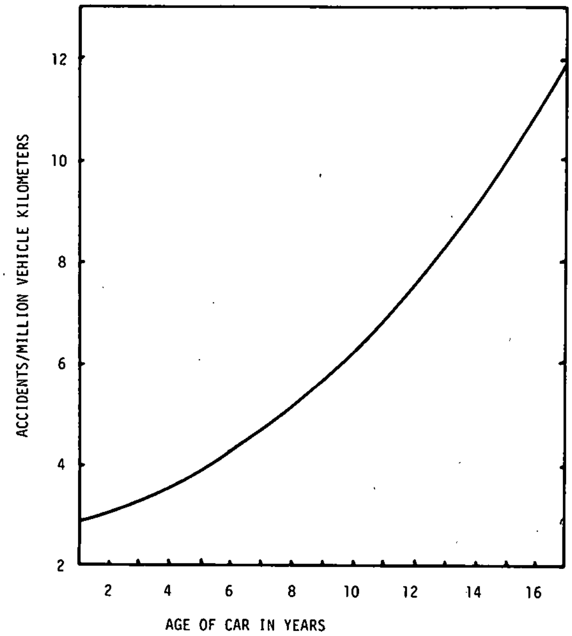


Figure 4. Accident involvement rate by age of automobile.



scrapped in the jth year is thus given by the following equation:

$$P_{i,j} = R_{i,j} * \exp - (W_{i,j}/T_j)^B \qquad (5)$$

where

$T_j = T_0 * A^j$,
A = repair cost growth rate of equation 4, and
B = Weibull slope of the repair cost distribution.

Figures 6 and 7 show comparisons, for 2 selected years (1965 and 1971), of the computed scrappage probability (shown as a percentage) and the actual values as derived from R. L. Polk data for those years. The figures also show the number of units scrapped as a percentage of total units scrapped. The scrappage probability distribution is anything but constant. In the period from 1960 to the early 1970s, both the slope and the peak of the distribution were increasing. Automobiles were getting scrapped earlier and at a higher rate. Median automobile life was decreasing. The present model provides a basis for representing the causal factors producing scrappage and for simulating probable future changes in this phenomenon.

The preceding outlines the general structure of the scrappage model. As noted, each automobile age class includes a breakdown of the number of automobiles by size and weight class. Currently, three size and weight classes are included. Unfortunately, available published data are inadequate to support the computation of scrappage probabilities directly by size class. The R. L. Polk data on cars in use are by manufacturer car division and are of little value in this regard. Some use can be made of the Polk car list counts, but there are special circumstances relating to the preparation of these counts that render them unsuitable for calibrating differential scrappage rates. It is clear from the available data, however, that large automobiles (standards, luxuries, and wagons) have longer median lives than small and intermediate automobiles. In the present model, therefore, total scrappage is first computed and the implied average median life is derived. Then, a realloca-

Figure 5. Percentage of repair costs less than X-dollars, 1970.

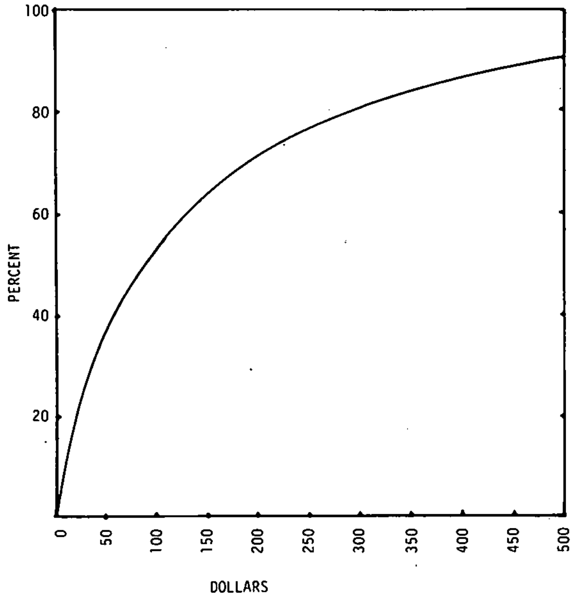


Figure 6. Percentage of automobiles in each model year scrapped during 1965.

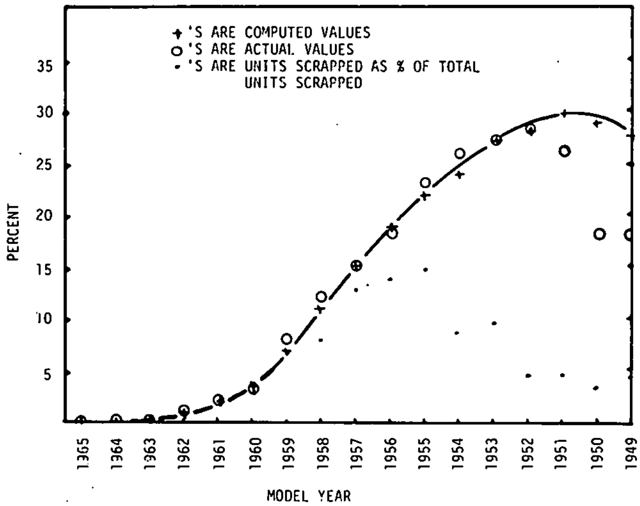
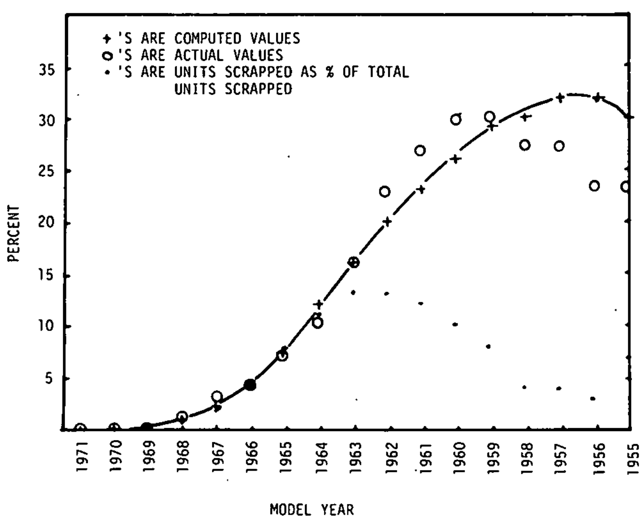


Figure 7. Percentage of automobiles in each model year scrapped during 1971.



tion is made by adjusting the expected median lives of large and small automobiles and redistributing the scrapped automobiles among the three size classes.

NEW AUTOMOBILE SALES AND SEGMENTATION MODEL

We turn now to the consideration of techniques employed for forecasting changes in market segmentation by automobile size (weight) class. The approach developed has proved to be an excellent means for projecting changes in the product mix. The technique involves the projection of trends in and then the modification of a set of so-called switching matrices, which represent the transition probabilities that the owner of one class of automobile will purchase the same class of automobile or one of the other classes of automobiles. Table 2 gives the transition probabilities for the 1970 switching matrix.

A set of logistic and exponential functions were developed, based on historic data on a new automobile buyer switching behavior to represent the trend or baseline projection. Embedded within the trend projection are the historic changes in automobile ownership patterns, costs of ownership, and costs of operation, each of which could be represented by an appropriate time-dependent equation. To the extent that a departure from the trend is projected in one of these underlying patterns (for example, a projection of the price of gasoline that departs from the historic gasoline price trend), the model computes and applies a new switching matrix based on a weighted time-scale change in new automobile purchase behavior.

Our implicit assumption is that the observed trend in switching behavior is a result of observable trends in the set of underlying factors. To the extent then that policy is used to change one or another of these factors in a predictable way, other things being equal, we argue that new automobile purchase behavior will be affected in a similarly predictable way. As an example, we may consider the effect of a tax on gasoline on the switching matrices. The historical trend in gasoline price P_i can be represented by an exponential function.

$$P_i = A * \exp(B * Y_i) \qquad (6)$$

where

A, B = constants and
Y_i = ith year.

Let P_i' represent the anticipated price of gasoline including the imposed tax. Since the cost of operation is only one of several factors affecting purchase behavior, we define

$$P^* = P_i + (P_i' - P_i) * W \qquad (7)$$

where W = weighting factor, which represents the relative weight of the cost of gasoline to total cost of personal transportation. We then determine a new value for the time variable Y_i to be used in the switching matrix equations as follows:

$$Y_i = \log(P^*/A)/B \qquad (8)$$

Table 3 gives the modified 1974 switching matrix based on an assumed average gasoline price of 59.1¢ in 1974 compared with the average of 39.0¢ in 1973.

Similar techniques could be applied for representing the effects of other government policy variables, e.g., a schedule of excise taxes on new automobile purchases based on, say, gross weight or fuel economy performance. In this case, the excise tax will change the relative prices of the different automobile size classes and will represent a departure from the unobservable past relative price movements. Again, a relative weighting factor is required that represents the strength of these price differences in relation to other factors influencing automobile-class selection.

This method tracks past changes in new automobile sales mix and has accurately projected the substantial market shift from 1973 to 1974. Figure 8 shows a plot on triangular coordinate paper comparing recent changes in new automobile sales mix, a trend projection, and a modified projection based on a particular forecast of gasoline price increases. The technique as currently applied, however, does not take account of (or attempt to forecast) the substantial leverage the automobile manufacturers could exert in the relative pricing of different automobile classes. It is clear that the automobile manufacturers could influence to a substantial degree the automobile-class switching behavior by relatively increasing or decreasing the price of one automobile class vis-à-vis another class.

The treatment of alternative government excise taxes or surcharges related to fuel economy could be treated in a relatively straightforward manner as a weighted change in cost of ownership (just as an increase in the price of gasoline represents a weighted change in the cost of operation) to determine the time-scale change in the trend switching behavior.

Within the scrappage model, each automobile-age class has associated its weighted average fuel consumption. The model thus computes, in relation to the use distribution equation as modified by projected gasoline price increases, total kilometers driven and total fuel consumed. In addition, the models have been used to test the effect of fuel supply constraints by reducing the kilometers that can be driven to match available fuel supply (if the unconstrained demand exceeds the supply) and recompute scrappage and sales. Similarly, gasoline rationing schemes have been tested, and the capability exists for testing the effects of other fuel conservation policies, e.g., a ban on Sunday driving.

The models have also been used in similar fashion to evaluate various emission control strategies. In this case, each model-year (age) class has assigned appropriate weighted average emission characteristics and their degradation characteristics over time. The models compute the emission burden year by year, e.g., total CO emissions, under various control strategies, such as a retrofit program, or alternative implementation dates for specific standards.

SOME RESULTS

The models under review represent an analytical tool that has been found particularly helpful for examining differential impacts of different policy choices and varying assumptions about market responses. Parameter

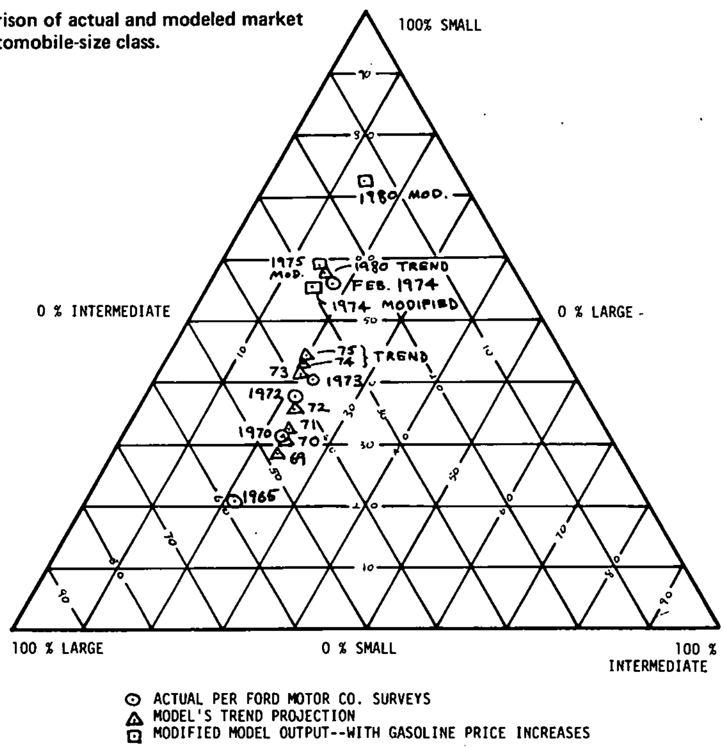
Table 2. 1970 switching matrix.

Size Class of Car Owned	Size Class of Car Purchased		
	Small	Intermediate	Large
Small	0.6153	0.2209	0.1638
Intermediate	0.2720	0.4194	0.3086
Large	0.1842	0.1680	0.6478
No previous car owned	0.6298	0.2398	0.1304

Table 3. 1974 modified switching matrix.

Size Class of Car Owned	Size Class of Car Purchased		
	Small	Intermediate	Large
Small	0.8480	0.1122	0.0398
Intermediate	0.5996	0.2522	0.1482
Large	0.3583	0.1295	0.5121
No previous car owned	0.9482	0.0362	0.0155

Figure 8. Comparison of actual and modeled market breakdown by automobile-size class.



values are easily changed, and the models have lent themselves to a variety of applications and different types of analyses. Since the models have not been used since mid-1974, there are no current results to report. Some typical results, however, from the prior work may be of interest.

The projected impacts of a number of assumptions on passenger automobile fuel demand and usage are given in Table 3. The assumptions were as follows: (a) an increase in the average price of gasoline as given in Table 4; (b) a 50 percent increase in sales-weighted average fuel consumption in 10 years (Table 4); and (c) an increase in the available supply of gasoline of 2 percent per year after 1974 (in 1974 there was 7 percent less available than was consumed in 1973). Table 4 gives model outputs for new automobile sales, gasoline consumption, and vehicle-kilometers.

Under this set of assumptions, total gasoline consumption peaks in 1982 and decreases slightly thereafter, but total vehicle-kilometers continues to increase. New automobile sales are depressed in 1974 and do not recover until 1977 to the point that would have been reached without the assumptions about fuel prices and availability. The actual drop in sales from 1973 to 1974 was greater than that projected in Table 4. The reason is that no allowance was made in the subject model run for the higher than normal rate of inflation and the consequent reduction in real disposable income.

Table 4. Typical model results.

Year	Avg Gasoline Price (¢/liter)	Sales-Weighted Avg Fuel Consumption (km/liter)	New Car Sales[a] ($)	Fuel Consumption[b] (liters)	Vehicle-Kilometers[b]
1973	10.3	5.25	11 219 000	284.9	1557
1974	15.6	5.45	9 963 000	265.0	1425
1975	16.7	5.65	10 469 000	270.2	1444
1976	17.9	5.86	10 989 000	275.7	1474
1977	19.1	6.08	11 507 000	281.1	1513
1978	20.5	6.31	12 008 000	286.8	1562
1979	21.9	6.55	12 479 000	292.5	1622
1980	23.4	6.79	12 914 000	298.4	1692
1981	25.1	7.05	13 313 000	304.4	1772
1982	26.8	7.31	13 602 000	307.5	1846
1983	28.7	7.59	13 790 000	306.7	1902
1984	30.7	7.87	14 053 000	304.9	1957
1985	32.9	8.17	14 392 000	268.5	2012

Note: 1 liter = 0.3 gal; 1 km/liter = 2.35 mpg; 1 km = 0.6 mile.
[a]Includes imports. [b]In billions.

Table 5. Change in product mix.

Year	New Car Sales (percent)			Total Cars in Operation (percent)		
	Small	Intermediate	Large	Small	Intermediate	Large
1969	28.4	23.2	48.4	23.4	17.8	58.8
1970	30.7	23.0	46.3	24.4	19.0	56.7
1971	32.4	22.8	44.7	25.4	19.9	54.6
1972	35.6	22.0	42.3	26.6	20.7	52.7
1973	41.3	20.1	38.7	28.0	21.3	50.7
1974	55.6	14.7	29.6	30.1	21.3	48.6
1975	58.8	14.2	27.0	33.3	20.7	45.9
1976	61.9	13.8	24.3	36.8	19.9	43.2
1977	64.8	13.6	21.6	40.6	19.0	40.4
1978	67.5	13.6	18.9	44.5	18.1	37.4
1979	70.0	13.6	16.4	48.6	17.2	34.2
1980	72.3	13.6	14.1	52.7	16.3	31.0
1981	74.3	13.7	12.0	56.7	15.5	27.7
1982	76.1	13.8	10.1	60.5	14.9	24.6
1983	77.5	13.8	8.7	63.8	14.5	21.7
1984	78.8	13.8	7.4	66.8	14.2	19.0
1985	80.0	13.7	6.3	69.5	14.0	16.5

Note: Based on the assumption that gasoline price will increase as given in Table 4 and other assumptions as stated in the text.

Table 5 gives the projected change in new automobile sales mix and the resulting change in the distribution of total automobiles in use by three size classes.

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1. R. P. Whorf. Models of Automobile Ownership. Proc., Conference on Transportation Research, Bruges, Belgium, 1973.