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REFERENCES

1. Y. Zahavi. Can Transport Policy Decisions Change Travel and Urban Structure? Presented at PTRC Education and Research Services, Ltd., Summer Annual Meeting, Univ. of Warwick, United Kingdom, 1978.
2. M. J. H. Mogridge. An Analysis of Household Transport Expenditures 1971-75. Presented at PTRC Education and Research Services, Ltd., Summer Annual Meeting, Univ. of Warwick, United Kingdom, 1977.
3. Y. Zahavi. The UMOT Project. U.S. Department of Transportation, DOT-RSPA-DPB-20-79-3, Aug. 1979.
4. A. Szalai, ed. The Use of Time: Daily Activities of Urban and Suburban Populations in Twelve Countries. Mouton Publications, Hawthorne, NY, 1972, pp. 117-123.
5. B.S. Bochner and D. G. Stuart. Analyzing Latent Travel Demands of Transit Dependents. Traffic Quarterly, Oct. 1978, pp. 563-581.
6. R. Herz. Periodische Komponenten der Zeitnutzung und ihre Bedeutung fur die Regionalplanung. Institute fur Stadtbau und Landesplanung, Univ. Karlsruhe, Karlsruhe, Federal Republic of Germany, 1978.
7. Y. Zahavi. Travel over Time. Federal Highway Administration, FHWA PL-79-004, Feb. 1979.
8. G. Roth and Y. Zahavi. Travel Time Budgets in Developing Countries. Presented at Conference on Personal Travel Budgets, Univ. of Leeds, United Kingdom, May 1979.
9. J. C. Bennet, R. H. Ellis, J. C. Prokopy, and M. D. Cheslow. A Comparative Evaluation of Intercity Modal-Split Models. TRB, Transportation Research Record 526, 1974, pp. 83-92.
10. R. T. Crow, K. H. Young, and T. Cooley. Alternative Demand Functions for Abstract Transportation Models. Transportation Research, Vol. 7, 1973, pp. 335-354.
11. N. K. Taneja. Airline Traffic Forecasting. Lexington Books, Lexington, MA, 1978.
12. FAA Aviation Forecasts, Fiscal Years 1979-1990. Federal Aviation Administration, 1978.
13. G. S. Cohen, N. S. Erlbaum, and D. T. Hartgen. Intercity Rail Travel Models. TRB, Transportation Research Record 673, 1978, pp. 21-25.
14. The Future of European Passenger Transport. Organization for Economic Cooperation and Development, Paris, 1977.
15. Survey of Current Business. Bureau of Economic Analysis, U.S. Department of Commerce, July 1979.

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Assessment of the Wharton EFA Automobile Demand Model

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The Wharton EFA Automobile Demand Model was developed in 1976 by Wharton Econometric Forecasting Associates, Inc., for the Transportation Systems Center of the U.S. Department of Transportation. This stock-adjustment econometric model is a large-scale model of automobile demand. It has been used widely by federal agencies in policy analyses. However, no major analyses of the model were performed before it was applied and, in some instances, the model was used inappropriately. This paper reports the results of an analysis of the model performed by staff of the Highway Safety Research Institute's Policy Analysis Division at the University of Michigan. The structure of the model was examined. An attempt was made to reconstruct the key time-series equations of the model, the forecasting ability of the model was examined, and sensitivity testing was performed. Computer tapes of the model and data used in the analysis were obtained from the Transportation Systems Center. The analysis uncovered several major problems with the model. New-car sales are partitioned into size classes by using an unjustifiable approach, and some major policy variables (for example, gasoline price) are employed unrealistically in the model. These and other problems combine to seriously weaken the forecasting and policy analysis capabilities of the model. Because of this, policy analysts should use the model only with extreme caution.

The Wharton EFA Automobile Demand Model was developed in 1976 by Wharton Econometric Forecasting Associates, Inc., for the Transportation Systems Center (TSC), U.S. Department of Transportation (1). It is one of the prominent analytic tools that have been developed for policy analysis related to the motor vehicle transportation system.

This stock-adjustment model of automobile demand consists of a system of about 400 equations and 600 variables. It is designed to forecast prices of new cars, total and composition of demand for new cars in the United States, vehicle miles traveled, miles per gallon by size class, scrappage, and other output of importance to the automobile industry. To make such forecasts, the model requires a wide variety of exogenous input that may be categorized as automobile characteristic, economic activity, demographic, policy, and transportation mode data variables.

In addition to its use in forecasting, the model is intended for policy analysis. For this purpose, a proposed policy is decomposed into its effects on the input components of the model, principally price of fuel, automobile excise taxes, automobile production costs, and similar elements. Usually, two forecasts of the market are made--one in the absence of the proposed policy, the other with policy changes fully incorporated into the model. The difference between the two forecasts constitutes an estimate of the effect of the policy.

There have been two main updates to the Wharton EFA automobile model. These are the Wharton EFA Motor Vehicle Demand Model, Mark I and Mark II (2,3). However, the initial version of the model has been the most widely used. Thus, that initial version of the model is discussed in this paper.

The construction of the Wharton EFA Automobile Demand Model was a very ambitious project that was completed under restrictive time constraints. As with any such project, unforeseen problems can arise that distort the accuracy of the model and decrease its usefulness. The limitations of this model are fairly subtle and required many hours of detailed examination to uncover. Nevertheless, these limitations severely reduce the usefulness of the model. This paper briefly presents some of the model's applications so that its past importance in policy analysis can be understood. Then the study approach and the model's structure are described. The paper concludes with a discussion of the more severe limitations of the model.

APPLICATIONS OF THE MODEL

The model has been used frequently in the U.S. Department of Transportation, particularly in the National Highway Traffic Safety Administration (NHTSA), the Office of Intermodal Transportation, and TSC. Other agencies that have used the model include the International Trade Commission in studies for the Senate Finance Committee, the U.S. Environmental Protection Agency, the Congressional Office of Technology Assessment, the Council of Economic Advisors, and the U.S. Department of the Treasury.

A variety of major policies has been analyzed; the most prominent among them are policies related to energy issues. Specifically, the model has been used by several agencies to study the economic impact of proposed automobile fuel-economy standards (4-6) and of the "gasoline guzzler" tax proposals (7). It has also been used to study the potential market impact of battery-powered automobiles (8), although the model was not designed for such a use. A more complete discussion of these documented uses of this model and other undocumented uses that deal with the impact of vehicle safety proposals, emission control standards, and other issues is presented by Saalberg, Richardson, and Joscelyn (9).

It appears that the model output has influenced the formulation of policy. There is, however, a wide variance of opinion on just how important a role the model has played. In any case, the limitations of the model have not been fully appreciated. Few, if any, analysts had time to become familiar with the structure of the model in the detail necessary to understand its performance. As a result, the model has been applied to situations it is not equipped to deal with (e.g., those that depend critically on the split between foreign and domestic shares of the market) and to situations in which reliance has been placed on inadequately qualified policy forecasts (e.g., those that involve the forecast shares of new-car sales by size class).

An analysis of the model by Golomb, Luckey, Saalberg, Richardson, and Joscelyn (10) disclosed many limitations of the model. These limitations would have been apparent to analysts in the government agencies that used the model if they had conducted an analysis of it with respect to its suitability for application to specific policy questions. However, such analyses require considerable time and money. Justifiable decisions to commit agency funds for such purposes require very close rapport and precise communications between agency managers and staff analysts capable of ascertaining the extent to which a given mathematical model is suited for application to a particular policy issue. That general problem applies to all potential uses of all models by government.

STUDY METHOD

The model analysis was divided into the following steps: analysis of the model structure, equation reconstruction, performance of the model in forecasting, and sensitivity testing. The analysis method used was based in part on the method presented by Dhrymes and others (11). Flow charts were constructed, and the computer program of the model was examined in detail to understand the structure of the model. An attempt was made to reconstruct the key time-series equations of the model. The historical data tapes that had been delivered to TSC by Wharton EFA were used in this attempt. In order to study the forecasting ability of the model, both the complete model and subsets of the complete model were run over the historical fit period of the model. Statistics on model errors were generated over these historical periods. Similarly, both the full model and subsets of it were used to perform sensitivity tests on the model. In these tests, policy-sensitive independent variables were changed by small percentages, and changes in the output variables were observed. In all tests performed, the computer program of the model and the data used were those developed by Wharton EFA and obtained from TSC. The interested reader is referred to Golomb and others (10) for a complete description of the study method used and the results of the analysis. This paper highlights only some of the findings of the analysis.

MODEL STRUCTURE

The model is essentially divided into six computational blocks. The blocks employ both exogenous and endogenous variables to generate a set of outputs. The major outputs and required exogenous inputs for each block are listed in Figure 1 (10, pp. 21-23), and the relationships among the blocks are shown in Figure 2 (10, p. 24).

In block A, estimates of fuel economy or miles per gallon for each of five size classes of new cars (defined on the basis of wheelbase length and price) are generated. Independently of block A, block B produces estimates of total purchase price for new cars by class and for each of the four components that make up the purchase price: transportation charges, base price, expenditures for options, and purchase taxes.

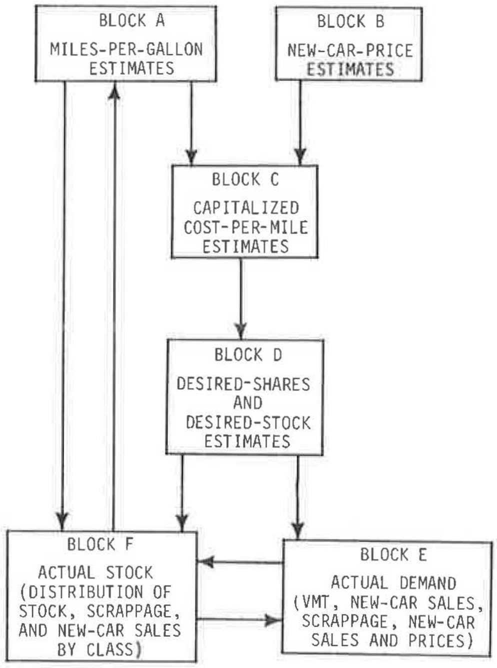
Blocks A and B feed into block C to calculate the capital cost per mile for each class of car. The capital cost per mile is essentially the present value of all costs associated with the purchase, sale, and operation of a car that has a 10-year lifetime. Essentially, block A, which has an exogenous gasoline price per gallon, provides the fuel cost component of the operating costs, and block B provides the estimate of purchase costs.

The capital cost-per-mile estimates are used in block D to calculate the desired stock of vehicles and the desired shares of stock for each of the five size classes. These estimates are of critical importance to the model because they constitute the targets toward which existing stock would move under the conceptual framework of the stock-adjustment process. Computation of the desired-share and desired-stock estimates is complex; it is done on

Figure 1. Wharton EFA Automobile Demand Model exogenous input and model output by block.

Model Exogenous Input	Model Output
Auto Characteristics Assumptions Curb Weight by Class Engine Displacement by Class Fraction of Cars with 4 Cylinders by Class Fraction of Cars with 6 Cylinders by Class Fraction of Cars with Overdrive by Class Fraction of Cars with Automatic Transmission by Class MPG Efficiency Factors by Class **Economic Activity Assumption** Ratio of City to Total Vehicle Miles Traveled	**BLOCK A** Miles Per Gallon Estimates for New Cars by Class • City • Highway • Combined • EPA Estimates
Economic Activity and Price Assumptions Transportation Price Index Foreign Auto Export Price Base Price Ratio of Class to Fixed Weight Average Index of Input Costs Consumer Price Index Real Disposable Income Maximum Price of Installed Options by Class Total State and Local Taxes on New Cars by Class **Demographic Assumptions** Number of U.S. Families	**BLOCK B** New Car Price • Transportation Charges by Class • Base Price by Class • Expenditures on Options by Class • Purchase Taxes by Class • Total New Car Price by Class
Economic Activity and Price Assumptions Finance Charge Discount Factor Gasoline Price Insurance Cost Index Tire Cost Index Parking, Tolls Cost Index Motor Oil Cost Index Repair Cost Index **Policy Variable** Total State and Local Taxes on New Cars by Class	**BLOCK C** Capitalized Cost Per Mile • Capitalized Cost Per Mile by Class
Economic Activity and Price Assumptions Ratio of Total Retail Outlets to Foreign Retail Outlets Real Disposable Income **Demographic Assumptions** Percent People Living in Metropolitan Areas Ratio of Pacific Population to Total Population Ratio of Mountain Population to Total Population Ratio of New England Population to Total Population Ratio of West South Central Population to Total Population Ratio of Resident Population, 20-29, to Total Number of Families Ratio of Families with 3 and 4 Members to All Families Number of U.S. Families Ratio of Families with 5 or More Members to All Families Licensed Drivers Per Family **Transportation Mode Assumption** Persons Traveling to Work by Non-Auto Means	**BLOCK D** Desired Shares and Desired Stock • Desired Shares by Class • Desired Shares/Domestic and Foreign • Desired Stock Per Family
Economic Activity and Price Assumptions Gasoline Price Real Disposable Income Unemployment Rate Scrap Metal Price Index Rate of Decline in Used Car Prices by Size Class	**BLOCK E** Actual Demand • Total Stock • Total Vehicle Miles Traveled • New Car Sales • Scrappage • Used Car Sales by Class • Used Car Prices by Class • Number of Trade-Ins by Age
Economic Activity and Price Assumptions Domestic Share of New Car Sales by Size Class Total Number of Makes of Cars by Class Real Disposable Income Number of Makes by Class Number of Dealers by Class **Demographic Assumptions** Number of Persons 25 Years and Older with 4 or More Years of College Ratio of Resident Population, 20-29, to Total Families Percent of Population in Metropolitan Areas Ratio of Pacific Population to Total Population Ratio of East North Central Populations to Total Population	**BLOCK F** Actual Stock • Scrappage Adjustment Factor • Scrappage Probabilities by Age • Shares of New Cars by Class • Cars in Operation by Class • Scrappage of Cars by Class • Shares of Cars by Class after Scrappage • Expected Scrappage for Older Cars • Mid-Year Stocks by Age • Average Age of Stock • Vintage-Weighted VMT

Figure 2. Flow diagram of Wharton EFA Automobile Demand Model.



the basis of the relative costs of different cars, the relationships of these costs to family income, and various other economic and demographic factors. The estimate of total desired stock is derived on the basis of desired shares, weighted capital cost per mile, family income, the number of licensed drivers, the number of U.S. families, and other economic and demographic variables.

In block E, total new car sales, scrappage, total stock, and total vehicle miles traveled are estimated. Each of these estimates is dependent on the other three, which makes the estimates highly simultaneous. New-car sales and scrappage also depend on the estimates of desired stock derived in block D as well as on variables of block F.

Block F contains two sets of equations: one to predict the stock of cars by class and by age and the other to predict the number of new cars by class. The predictions for the total stock by age depend on new-car sales estimated in block E and a vehicle-survival model that determines the scrappage of cars by age. The scrappage estimates in the vehicle-survival model depend on the total scrappage estimate of block E. The estimation of new-car sales by size class depends on the desired-stock share estimates generated in block D and on the actual or existing number of cars on the road of that size class after scrappage, which is predicted within block F. The estimation of the foreign and domestic shares of new-car sales by size class is made exogenously.

MODEL LIMITATIONS

Desired Stock

Basic to the Wharton EFA automobile model is its treatment of the demand for automobiles as if, given prices, incomes, and other factors, society desired to own a specified total number of vehicles. The number of new cars purchased in any year is then treated as dependent on the difference between the number of cars desired and the number already registered and on the road. Of course, it is not implied that automobile buyers actually think in such terms. Rather, the stock-adjustment process is employed as a statistical shortcut to embody the effect of used-car prices on new-car demand.

The net cost of a new car to a buyer is the difference between the price he or she must pay for the new car and what he or she can get for a used car as determined by supply and demand on the used-car market. In general, the larger the number of cars already on the road, the lower the price of used cars and, hence, the greater the cost of trading. For this reason, the supply of used cars already in operation acts as a back pressure on the demand for new cars, and this back pressure is captured by the stock-adjustment representation of new-car demand.

The use of the stock-adjustment mechanism in the Wharton EFA automobile model is damaged, however, by the way in which the desired stock was estimated. The Wharton EFA authors fitted automobile ownership per family to price and income data drawn from a cross section of states. Unfortunately, the small variation in new-car prices among states makes it difficult, if not impossible, to obtain an accurate estimate of price elasticity by this procedure. The problem shows up clearly in the Wharton EFA calculation for desired stock:

ln (desired stock per family) = -1.910 [0.796] + 0.563[0.180] ln (real permanent income per family) - 0.101 [0.052] ln (index of income distribution) - 0.200 [0.238] ln (average cost per vehicle mile driven) + 0.421 [0.137] ln (licensed drivers per family) - 0.054 [0.036] ln (nonautomobile commuters per family) + 0.099 [0.062] (percentage of persons living in metropolitan areas),

where $\bar{R}^2$ = 0.461. In this calculation, permanent income is the income that a family can expect in the long run, as distinguished from what is received during any particular year. The index of income distribution is the ratio of the number of families that have incomes of at least $15 000 to the number that have incomes under $15 000. Average cost per vehicle mile driven is the present value of the total cost per mile of owning and operating a vehicle, discounted over the lifetime of the car. It includes the price of the new car as well as all operating costs, insurance, and repairs. The other variables in the equation are self-explanatory.

Figures in brackets are standard errors of the respective coefficients. In keeping with the small state-to-state variation in prices, the price effect is measured with the least accuracy of all the variables in the calculation. Indeed, the coefficient is not statistically different from zero. In other words, the estimated equation provides no evidence that desired stock responds in any way to changes in price.

An additional difficulty with the desired-stock equations as measured is that the estimation procedure focuses entirely on the number of cars, to the exclusion of the age distribution of the stock of cars owned. The wide state-to-state differences in the age distribution of cars on the road is not taken into account.

Desired Stock by Size Class

To produce estimates of new-car sales by size class, the Wharton EFA automobile model partitions total desired stock into shares by size class. This procedure has neither basis in theory nor validity as an empirical shortcut. The stock-adjustment process is widely used in the modeling of automobile demand and performs well in its shortcut role as long as attention is fixed on total demand; however, it is unclear that the demand for new subcompacts, for example, is usefully represented as deriving from a gap between the desired stock of subcompact cars and the number already registered. One need only consider the present situation to see the weakness of the idea. Uncertainty of fuel availability and price have increased the demand for very small, fuel-efficient cars. But the would-be buyers of these cars are owners of large cars that must be traded. Despite the small size of the existing fleet of subcompact cars on the road, a substantial back pressure is being exerted on the purchase of subcompact cars by the reluctance of buyers of used cars to purchase additional large cars. However, note that there are variables in the desired-stock-share equation that will lessen this back pressure. Specifically, these variables allow trading among size classes.

Block D contains a system of five equations designed to generate the desired stock of the five classes employed in the model. The most-important variables that affect these proportions are discounted operating cost per mile of the respective car sizes and average family income relative to the average cost per mile of all cars.

Like total desired stock, the share equations are fitted to data from a cross section of states, again employed without taking account of differences in age structure. In view of the ability of prospective buyers to choose not only among a range of sizes and prices of new cars but also among a range of ages and prices of used cars, the validity of using an observed cross section to predict market shares is open to serious question.

Effect of New-Car Prices on New-Car Sales

New-car prices enter the Wharton EFA automobile model via the equation of new-car sales (calculation 2) in two ways. According to this calculation, total sales depend on the desired stock of cars, which already embodies the price of new cars. In addition, the Wharton EFA equation makes new-car sales dependent on the rate of increase in new-car prices:

ln (new sales per projected stock) = -2.915 + 3.793 [0.383] ln (desired stock per projected stock) + 6.039 [0.728] ln (permanent income per current income) - 1.267 [0.367] (rate of increase in new-car prices) - 0.225 [0.103] (dummy for strikes),

where $\bar{R}^2 = 0.864$. Projected stock is the number of cars that would be found on the road in the absence of any new-car sales. It is equal to the total stock as of the end of the preceding year less scrappage. Standard errors are in brackets.

The way new-car prices appear in the calculation creates additional weakness in the model. Aside from its insignificant contribution to desired stock, the only way the price of new cars appears in the automobile-demand equation is as its rate of increase. The theoretical background of this variable is unclear, yet the model will apply this coefficient to any increase in price expected from policy actions and will automatically attribute to such actions an initial, substantial, but temporary impact on sales of new cars.

The only role for the level, as distinguished from the rate of increase, of new-car prices is via the desired stock. The price of new cars represents approximately one-half of the discounted operating cost, but, as shown above, the effect of operating cost on desired stock is not measured with precision, nor even with statistical significance.

The combination of these two highly uncertain components of the new-car sales equation will produce cyclical responses by the model to any one-time change in prices of the sort expected from most policy decisions. The model will translate any one-time price increase into an immediate reduction of new-car sales, via the rate of increase variable. In all following years, however, when prices are stabilized at the higher level, rate of change drops to zero and the large negative impact is removed. But the temporary drop in sales has been so great that the model will find actual stock deficient relative to desired stock, and the forecast of total sales will rebound above the base level despite the higher level of prices.

Price differences play a minimum role in the allocation of new-car sales among size classes. Once the model determines total sales, it assigns them to size classes exclusively on the basis of the composition of the size class of desired stock relative to the composition of existing stock. Price enters only in the partitioning of desired stock. Analysis of the size composition of new-car sales demands a more complex and sophisticated treatment than the stock-adjustment mechanism can provide, and it is no surprise to find that the performance of the Wharton EFA automobile model is substantially weaker in predicting the composition of new-car sales than it is in predicting the overall total.

Imports Versus Domestic Production

In the initial version of the Wharton EFA automobile model, the imported share of U.S. new-car sales by size class is a preassigned input. In other words, despite the substantial share of sales of small cars that have long been imported by U.S. consumers, the model is incapable of forecasting how imports respond to new conditions. Inasmuch as an important function of the model is supposed to be the prediction of market shares by size classes, inability to forecast the imported share of the market raises serious additional questions about its utility. This problem has been addressed in revised versions of the model; however, it is raised here because the model has been used in one instance, by the International Trade Commission, to forecast the split between foreign and domestic shares when, in fact, the foreign-domestic split of each size class was set exogenously (7,12).

Forecasting Performance of the Model

When the performance of the model is tested against data for the period 1960-1974 (included in the data to which the statistical equations were fitted), sales of new cars were found to be predicted with errors that average about 9 percent. Forecasts of vehicle miles traveled per family were more accurate; those errors averaged about 5 percent. In contrast, however, predictions of market shares by size class were uniformly poor. Errors in forecasts of market shares ranged from an average of about 14 percent for luxury vehicles and 37 percent for full-size cars up to 54 percent for midsize and 97 percent for subcompact models. Errors for all size classes were larger than would be produced by a naive sample mean model, even over the data to which they were fitted. Error statistics for eight key output variables of the model are shown in Table 1 (10, p. 173). The remarkably poor performance of the model in forecasting market shares is in keeping with the stock-adjustment nature of the Wharton EFA automobile model and with the use of state-by-state data to develop estimates of desired composition of automobile ownership.

POLICY RESPONSES OF THE MODEL

The response of the model to changes in policy is most easily represented by the percentage change in forecast that results from a percentage change in a policy-sensitive input variable. These are calculated by first obtaining a base forecast from the model in the absence of any change. The policy change is then incorporated in the exogenous input and a second forecast is made. The difference between the two forecasts represents the effect of the policy as predicted by the model.

The structure of the model embodies two general classes of policy-sensitive variables:

1. Variables that affect the selling price of new cars. This includes, for example, excise taxes on new vehicles, transportation charges, and prices of options. The most important of these, the index of automobile production costs, is generally representative of the others.
2. Variables that affect costs per mile of operation independently of initial purchase price. This class of variable includes automobile characteristics, insurance rates, tire prices, and parking fees. The price of gasoline is the most important variable in the class and is generally representative.

To understand the effect of these variables in the model, it is necessary to follow each set of forecasts over a period of years.

Tables 2 and 3 cover a 15-year period of forecast responses to changes in each of these two key policy variables. To provide a historical context, each of the analyses is examined as if the policy change had been initiated in 1960, and impacts are followed through 1974.

Production Cost of Automobiles

According to the model, a 1 percent increase in production costs would reduce total sales by 1.46 percent in the initial year, but for 8 years thereafter would raise sales above levels that would have prevailed at lower prices. Beyond year 9, however, total sales would again be slightly lower than otherwise. In terms of the number of cars sold, the model predicts that, following the initial decline, sales during the remaining 14 years would total 0.3 percent more cars than would have been

Table 1. Error statistics for the within-sample period 1960-1974.

Variable	Mean	Root-Mean-Square Error	100 x Root-Mean-Square Error/Mean
Sales	8.693	0.8234	9.47
Scrappage	6.171	0.8958	14.52
Vehicle miles traveled per family	12.38	0.6358	5.134
Subcompact car	0.1339	0.1300	97.08
Compact car	0.1697	0.0572	33.68
Midsize car	0.2520	0.1356	53.81
Full-size car	0.3628	0.1294	35.66
Luxury car	0.0814	0.0113	13.90

Table 2. Percentage response to a 1 percent increase in automobile production costs.

Year	Total New Car Sales	Size Composition of New Sales: Subcompact	Compact	Midsize	Full-Size	Luxury	Vehicle Miles Traveled
1	-1.46	0.75	-0.30	0.01	-0.45	-0.01	-0.07
2	0.77	0.12	0.06	-0.03	-0.14	-0.01	-0.23
3	0.05	0.17	-0.02	-0.02	-0.13	-0.01	-0.13
4	0.02	0.19	-0.04	-0.02	-0.12	-0.01	-0.09
5	0.12	0.43	-0.14	-0.00	-0.28	-0.01	-0.08
6	0.09	0.46	-0.13	0.01	-0.32	-0.01	-0.04
7	0.09	0.61	-0.17	0.02	-0.45	-0.01	0.08
8	0.10	0.76	-0.17	0.01	-0.58	-0.02	0.03
9	0.09	0.85	-0.18	-0.03	-0.61	-0.03	0.06
10	-0.00	0.84	-0.21	-0.04	-0.57	-0.03	0.09
11	-0.07	0.72	-0.18	-0.03	-0.50	-0.02	0.10
12	-0.17	0.73	-0.02	-0.01	-0.33	-0.02	0.09
13	-0.11	0.24	0.03	0.02	-0.27	-0.01	0.06
14	-0.15	0.19	0.05	0.03	-0.26	-0.01	0.04
15	-0.14	0.16	0.04	0.02	-0.21	-0.01	0.02

Table 3. Percentage response to a 1 percent increase in gasoline prices.

Year	Total New Car Sales	Size Composition of New Sales: Subcompact	Compact	Midsize	Full-Size	Luxury	Vehicle Miles Traveled
1	-0.20	0.09	0.05	0.01	-0.15	0.00	-0.20
2	-0.22	0.06	0.05	0.00	-0.11	0.00	-0.21
3	-0.23	0.07	0.04	0.00	-0.11	0.00	-0.22
4	-0.07	0.06	0.03	0.00	-0.10	0.00	-0.24
5	0.01	0.10	0.00	-0.00	-0.11	0.00	-0.25
6	0.06	0.12	0.00	0.00	-0.12	-0.00	-0.25
7	0.07	0.12	-0.00	0.01	-0.12	-0.00	-0.24
8	0.05	0.17	-0.01	0.00	-0.15	-0.00	-0.23
9	0.04	0.16	-0.01	-0.01	-0.14	-0.00	-0.21
10	-0.01	0.17	-0.02	-0.01	-0.13	-0.00	-0.20
11	-0.02	0.14	-0.02	-0.01	-0.10	-0.00	-0.19
12	-0.05	0.12	-0.01	-0.01	-0.10	-0.00	-0.19
13	-0.07	0.11	-0.00	-0.00	-0.10	-0.00	-0.19
14	-0.08	0.09	0.01	0.00	-0.10	-0.00	-0.20
15	-0.09	0.13	0.01	0.01	-0.14	0.00	-0.21

sold in the absence of a price increase.

Increased production costs also generate a shift in the forecast composition of sales, and the sale of subcompacts increases, largely at the expense of full-size cars. Again, a cyclical pattern over the experiment period is in evidence as the increase in subcompact share declines from an initial 0.75 percent to only 0.12 percent in the year following, then rises again by year 9 to exceed the initial gain, only to decline to 0.16 percent in the 15th year. Similar cycles appear in the compact and full-size share of the market.

The model's projection of vehicle miles traveled is particularly unrealistic. Initial levels are below and later levels are above what would be found in the absence of any change in automobile production cost.

Price of Gasoline

In response to a 1 percent increase in the price of gasoline, the model again generates cycles over the experimental period. New-car sales are depressed for four years, followed by five years at levels above what would have prevailed with cheaper gasoline, then lower levels recur. With higher gasoline prices, the model shifts the composition of sales in the direction of small cars, but once more in a characteristic cyclical pattern. A particularly strange aspect of the predicted size distribution is that the principal trade-off occurs between subcompacts and full-size cars. Compacts and mid-size cars show little change, and luxury cars show practically no change.

Based on the evidence available, one cannot say whether the model will continue to generate cycles in the longer term. It may be that this behavior dampens out in future years. However, in the applications of this model, 15 years has been a typical forecast period. Therefore, these cycles pose serious problems for the model users.

CONCLUSIONS

Like any large econometric model, the Wharton EFA Automobile Demand Model is intended to approximate the complex interrelationships in an economic subsystem. A successful approximation is capable of processing large amounts of data to produce detailed forecasts of policy impacts. In view of the growing complexity of policy issues, there is every reason to believe that government agencies and others will continue to employ such models and will expand the area of their application.

But the validity of any model depends on how closely its structure matches that of the system it is supposed to approximate. Even a model that, in retrospect, forecasts well over the data to which it has been fitted will produce substantial errors in future forecasts and generate misleading policy analyses if it contains structural elements that are seriously at variance with reality.

Unfortunately, this is the case with the Wharton EFA automobile model; it is seriously deficient in at least two key respects: The model employs prices in an unrealistic manner in the generation of total new-car sales, and total sales are partitioned into size classes by a structure that is worse than no model at all, even over the sample data.

Since practically all applications made of the Wharton EFA automobile model depend critically on one or both of these features, policymakers who intend to employ the model in their analyses are advised to be on guard. Note that this advice applies not only to users of the Wharton EFA automobile model but also to users of all policy models. Every model has its limitations, and these should be recognized by model users.

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REFERENCES

1. G.R. Schink and C.J. Loxley. An Analysis of the Automobile Market: Modeling the Long-Run Determinants of the Demand for Automobiles; Simulation Analysis Using the Wharton EFA Automobile Demand Model; Appendices to the Wharton EFA Automobile Demand Model. Transportation Systems Center, Cambridge, MA, DOT-TSC-1072, 1977, 3 vols.
2. C.J. Loxley, T. Osiecki, K. Rodenrys, and S. Thanawala. Revisions to the Wharton EFA Automobile Demand Model: The Wharton EFA Motor Vehicle Demand Model (Mark I). Wharton EFA, Inc., Philadelphia, draft rept., 1978.
3. C. Loxley, T. Osiecki, and K. Rodenrys. The Demand for Light Duty Trucks: The Wharton EFA Motor Vehicle Demand Model (Mark II). Wharton EFA, Inc., Philadelphia, draft rept., 1978.
4. Data and Analyses for 1981-1984 Passenger Automobile Fuel Economy Standards, Document 1: Automobile Demand and Marketing. National Highway Traffic Safety Administration, U.S. Department of Transportation, 1977.
5. Final Impact Assessment of the Automotive Fuel Economy Standards for Model Year 1981-1984 Passenger Cars. National Highway Traffic Safety Administration, U.S. Department of Transportation, 1977.
6. Rulemaking Support Paper Concerning 1981-1984 Passenger Auto Average Fuel Economy Standards. National Highway Traffic Safety Administration, U.S. Department of Transportation, 1977.
7. U.S. International Trade Commission. The Gas Guzzler Tax Proposal: A Comparison of Its Impact with That of the Fuel Efficiency Incentive Tax Proposal upon the Future of the U.S. Passenger Automobile Industry. Committee on Finance, United States Senate (95th Congress, 1st Session), U.S. Government Printing Office, Sept. 1977.
8. E.P. Marfisi, C.W. Upton, and C.E. Agnew; Mathtech, Inc. The Impact of Electric Passenger Automobiles on Utility System Loads, 1985-2000. Electric Power Research Institute, Palo Alto, CA, 1977.
9. J.H. Saalberg, B.C. Richardson, and K.B. Joscelyn. Federal Policy Applications of the Wharton EFA Automobile Demand Model. UMI Research Press, Ann Arbor, MI, 1979.
10. D.H. Golomb, M.M. Luckey, J.H. Saalberg, B.C. Richardson, and K.B. Joscelyn. An Analysis of the Wharton EFA Automobile Demand Model. UMI Research Press, Ann Arbor, MI, 1979.
11. P.J. Dhrymes, E.P. Howrey, S.H. Hymans, J. Kmenta, E.E. Leamer, R.E. Quant, J.B. Ramsey, H.T. Shapiro, and V. Zarnowitz. Criteria for Evaluation of Econometric Models. Annals of Economic and Social Measurement, Vol. 3, 1972, pp. 291-324.
12. U.S. International Trade Commission. The Fuel

Efficiency Incentive Tax Proposal: Its Impact upon the Future of the U.S. Passenger Automobile Industry. Committee on Finance, United States Senate (95th Congress, 1st Session), U.S. Government Printing Office, July 15, 1977.

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Forecasting Equilibrium Motor Vehicle Holdings by Means of Disaggregate Models

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This paper reports on the development of a methodology to forecast the fuel efficiency of household motor vehicle holdings in the United States. Forecasts are made by using a new partial equilibrium model of the operation of the motor vehicle market. In a break with the prevailing aggregate stock-adjustment approach, the approach described here incorporates household-level discrete choice models to explain vehicle holdings and scrappage decisions. Given assumptions on the design and prices of future new vehicles and fuel prices, the behavior of a demographically weighted sample of households is simulated and equilibrium conditions for the vehicle market are solved each year in the forecast period. The paper presents predictions of household vehicle holdings, new-vehicle sales, used-vehicle scrappage, and the resulting average vehicle fuel efficiencies under two future scenarios.

The years ahead will be characterized by significant changes to the motor vehicle market. In particular, the federal vehicle fuel-economy standards enacted in 1975 have stimulated domestic manufacturers to launch major programs of vehicle redesign. At the same time, fuel prices are expected to rise considerably. A further development that affects the vehicle holdings is the projected shift in the demographic mix of the population toward an older, more affluent profile and more small households.

Because the gasoline used by household motor vehicles constitutes a substantial fraction of American oil consumption, forecasts of vehicle fuel efficiencies are clearly relevant to the formation of a national energy policy. Our work addresses two forecasting questions:

1. Given the currently envisioned changes in vehicle design, what is the likely path of sales-weighted new-vehicle efficiencies through 1985?
2. Given the same design assumptions, how will the average efficiency of all vehicle holdings change over time?

To answer the first question, one must predict the composition of new-vehicle sales. To answer the second, one must predict not only the mix of new-vehicle sales but also the volume of new-vehicle sales and the rate of used-vehicle scrappage as well. The forecasts to be presented here are the output of a new partial equilibrium model of the operation of the motor vehicle market and of machinery for forecasting with this model.

Our approach to forecasting vehicle sales, scrappage, and holdings breaks completely with the aggregate stock-adjustment framework that has long prevailed. Aggregate stock-adjustment models generally contain three elements:

1. A system of aggregate demand models predicts desired vehicle holdings,
2. Descriptive models predict used-vehicle scrappage, and
3. Stock-adjustment equations predict new-vehicle sales.

This three-step procedure was first suggested, independently, by Chow (1) and by Nerlove (2). Wharton Econometric Forecasting Associates (3) presented a particularly sophisticated application, and Ayres and others (4) and Mellman (5) provided literature reviews.

Our decision to reject the aggregate-stock-adjustment paradigm for the approach used here follows from a comparison of basic elements of model structure. Stock-adjustment models characterize desired vehicle holdings as the classical demands of a representative consumer. We, in contrast, model holdings as the discrete choices of a population of heterogeneous consumers. Stock-adjustment models explain new-vehicle sales as the fractional reduction of discrepancies between desired and actual vehicle stocks. We treat new-vehicle sales, used-vehicle scrappage, and used-vehicle prices as jointly endogenous variables that solve a set of market equilibrium conditions. In these and other regards, our forecasting system, although itself idealized, provides a more realistic representation of the vehicle market.

CONSUMER BEHAVIOR

The owners of motor vehicles participate in the operation of the vehicle market in two ways:

1. Through their demand for new and used vehicles from the market and
2. Through their supply of used vehicles to the vehicle and scrap markets.

Often, although not always, the demand and supply roles occur in conjunction. In particular, when a consumer trades in a used vehicle for a new one, he or she is simultaneously acting as a vehicle demander and supplier. On the other hand, when someone decides to add a vehicle to current holdings, he or she acts only as a demander; when one decides to subtract a vehicle, he or she acts only as a supplier. In what follows, models of the demand and supply aspects of consumer behavior are described.

Vehicle Demand

The household's choice of a quantity of vehicles to own, its selection among alternative types of vehicles, and its subsequent use of the vehicle selected should, in principle, be modeled as an interrelated complex of decisions. Our efforts were