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Forecasting Equilibrium Motor Vehicle Holdings by Means of Disaggregate Models

CHARLES F. MANSKI AND LEONARD SHERMAN

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 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 more limited in scope. The absence of data on vehicle use by our household sample precluded any attempt to model use or its relation to vehicle holdings, as in Lerman and Ben-Akiva (6). Moreover, in modeling vehicle holdings, we found it desirable to focus resources on the problem of modeling household selection among vehicle types conditional on choice of a vehicle quantity. Correspondingly, we restricted our efforts to explain vehicle quantities to the development of a reduced-form model. This allocation of research priorities followed from a belief that projected vehicle design and price changes will have their major impact on the composition of vehicle holdings. But we, on the contrary, expect that the number of vehicles that households choose to own will be largely determined by socioeconomic and demographic forces.

The model that explains vehicle quantities yields the probability that a household characterized by a given income, size, residential location, number of workers, age of head, and previous year ownership level will currently hold zero to three vehicles. A multinomial logit form was estimated from a sample of 810 households surveyed in June 1978. A detailed description of this model can be found in Sherman, Manski, and Ginn (7).

Our model of the household's choice among alternative vehicle types, plus the related model of vehicle scrappage decisions, form the heart of the model of the motor vehicle market. Because the vehicle choice model has been described in detail in Manski and Sherman (8), we limit ourselves here to a summary of the specification and results.

Two vehicle submodels were estimated--one to explain vehicle choices in households that hold a single vehicle, the other to explain the composition of holdings in two-vehicle households. In each case, we view the household as making yearly evaluations of its current vehicle holdings and updating these as desired. The utility of any vehicle, or vehicle pair, is assumed to be a function of vehicle seating capacity, luggage capacity, weight, acceleration time, noise level, scrappage probability, price, operating cost, and a search-transaction cost associated with entering the vehicle market. Search-transaction costs can be avoided by staying out of the vehicle market, that is, by retaining current holdings. Household size, age, education, income, number of workers, and residential location condition the utility function.

The empirical analysis was based on a national random sample of households drawn in 1976 from the Survey Research Center's rotating consumer panel. This sample contained 430 usable observations on vehicle choices by one-vehicle households and 445 on those by two-vehicle households.

The Survey Research Center's sample contained only 150 households that owned three or more vehicles. It was decided that this sample was too small to support an estimation of a model of vehicle choice by such multiple-vehicle households. In producing our forecasts, coefficients estimated in the two-vehicle model were used to predict the vehicle choices of households that own three or more vehicles.

From a variety of sources, we developed a vehicle-attributes file that provides the relevant design, performance, and price data for the various makes, models, and vintages of passenger automobiles and light trucks available in the United States in 1976. Multinomial logit models were used to probabilistically describe each household's choice among vehicle alternatives. A household's choice set would, in general, contain all vehicles or vehicle pairs available on the marketplace plus whatever vehicles are currently held by the household. The latter are characterized by a zero search-transaction cost.

Among the many empirical results, one prominent finding is that the marginal utility of additional vehicle seats varies considerably with household size. Moreover, households that own two vehicles tend to want smaller ones than do single-vehicle households. Heavy vehicles are found desirable by older households but weight is of no concern to younger ones. As expected, luggage space is viewed as a positive characteristic.

We find that most aspects of vehicle performance have little effect on choices but, counterintuitively, sluggish vehicles appear to be strongly preferred to quick ones. No convincing explanation for this result has yet emerged, although it has been suggested by some that the model's omission of measures of maintenance cost might make quick vehicles appear undesirable.

Vehicle costs, including price, fuel costs, and search-transaction costs, are all found to be important determinants of vehicle utility. Of some interest is the fact that the impact of fuel costs seems to vary considerably among socioeconomic and demographic groupings. This variation may mask differential vehicle-use patterns among the groups. The large magnitudes of the search-transaction cost coefficients in the estimated models indicate that, if all else is equal, retention of one's current holding is much to be preferred to entrance into the vehicle market. Households enter the market only when the gains from doing so exceed the costs incurred.

Vehicle Supply and Scrappage

We assume that the household that is disposing of a vehicle faces a binary choice between scrappage and sale on the vehicle market. Scrappage yields a price R_j and market sale yields a price P_j. The household scraps the vehicle if $P_j < R_j$; otherwise, it sells it. It is assumed that there is no linkage between a household's decision about vehicle holdings and the sales-scrappage price the household can realize from disposal of currently held vehicles. It can be shown that decisions about holdings are in fact independent of disposal prices if two conditions are satisfied:

1. Household utility functions should exhibit constant marginal utility of money and
2. The price received for disposal of a vehicle should not depend on the identities of any other vehicles simultaneously disposed of or purchased; that is, market transactions should not be package deals.

The market price (P_j) undoubtedly depends on the mechanical condition, body quality, and installed optional equipment of vehicle j. Although such detailed vehicle attributes and their effects on price may be known to the vehicle owner, they were not available to us. Rather, the only price statistics in our possession were the Red Book prices (9), published measures of the average realized sales prices for each make, model, and vintage of vehicle.

Given this, we formulated a simple probabilistic scrappage-model conditioning based on the known Red Book (9) price. Specifically, by letting V_j be vehicle j's Red Book price, we assumed that

$$\text{Prob}\,[P_j < R_j] = \alpha R_j/V_j \qquad (1)$$

for some $\alpha > 0$. This model can be derived from more basic assumptions, but its greatest virtues are its reasonable qualitative properties and its simplicity.

Since scrappage prices vary relatively little among vehicles, we further assumed that $R_j = R$, a constant for all j. The scrappage probability then reduces to β/V_j where $\beta = \alpha R$. Given data on make-model-vintage-specific scrappage and sales frequencies in the United States, β can be estimated by least-squares regression. The point estimate obtained was $\hat{\beta} = 250$. A check on the reasonableness of the estimate and of the model more generally emerges if we observe that, under the model, V_j should never fall below β. In fact, the lowest vehicle Red Book prices are around $300, so that $V_j > \hat{\beta}$ always.

Organizations, including police forces, utilities, taxi companies, rental car agencies, and numerous other government agencies and private firms collectively account for significant fractions of motor vehicle holdings, purchases, sales, and scrappage. Little is known about the determinants of organizational vehicle-holdings behavior or about the extent to which the organization and household sectors of the motor vehicle market are interconnected. Casual observation does, however, suggest that organizations usually buy new vehicles rather than used ones and that the used vehicles they do purchase are generally bought from other organizations rather than from households. On the other hand, organizations often sell used vehicles to households; thus the organization sector becomes a net supplier of used vehicles to the household sector of the vehicle market.

It is estimated that, in recent years, organizations have supplied about 1.5 million vehicles/year to households. For forecasting purposes, we have assumed that the rate of supply will grow by 0.05 million vehicles each year through 1985 and that the composition of supply is identical to that in the overall used-vehicle fleet.

The firms that supply new motor vehicles and the consumers who purchase them are not treated symmetrically in the market model. As was indicated earlier, we assume that, at the beginning of each sales year, manufacturers make new-vehicle design and pricing decisions that are then fixed for that year. With the new-vehicle offerings specified, new-vehicle supplies are assumed to be perfectly elastic until the end of the sales year, when production ceases.

The above assumptions are fairly, although not totally, realistic. Certainly vehicle designs, once embodied in production facilities, are not easily altered. Moreover, when production facilities are in place, marginal costs of production are relatively constant over a wide range of quantity levels. As long as constant marginal costs prevail, the assumption of perfectly elastic vehicle supplies is reasonable, at least up to a point. There are limitations to production capacity that ultimately constrain vehicle supply. And, in fact, with the rapid conversion of manufacturing plants to gear them for the production of more fuel-efficient vehicles, order backlogs and delivery delays are becoming more frequent occurrences for popular models. Perhaps least realistic is our assumption that prices of new vehicles are fixed over the sales year. Although price setting by manufacturers is an administered process, prices are not rigid. Mid-year changes in wholesale and retail prices are being observed with increasing frequency. In addition, dealers often adjust wholesale to retail markup levels as market conditions change.

Abstracting from their realism, the assumptions are necessary for analytic tractability. The problem of modeling the operation of the vehicle market would be substantially complicated if we allowed manufacturers to make supply adaptations during the yearly market period. It is far simpler to model the market dynamic as a sequential process in which manufacturers act, then consumers bring the market to a temporary equilibrium, then manufacturers act again. The model can, of course, be exercised on a quarterly rather than yearly simulation cycle, were the issue of mid-year price adjustments of sufficient concern to justify the added costs of a computer run. As stated earlier, a scenario rather than a formal model forms the basis for our projections of future manufacturer design-pricing behavior.

MARKET EQUILIBRIUM

The motor-vehicle market shares with the housing and certain other durable-goods markets a number of complex features. First, vehicles are multidimensionally differentiated and spatially located commodities. In fact, every used vehicle, because of its unique body and mechanical condition and location, represents a distinct good. Second, vehicle trade occurs in an environment of very limited information. Potential sellers and buyers are often not aware of each others' existence. Moreover, buyers generally have only partial knowledge of vehicle attributes, and learning is costly. Third, the trading process usually involves one-on-one negotiations, whose outcomes can depend on the strategic behavior of participants.

Clearly, practical modeling of the market's operation requires considerable idealization. An obvious approach is to assume that, given new-vehicle designs and prices, used-vehicle prices adjust until the demand for used vehicles equals the available supply. Specifically, let A_u represent the universe of extant used-vehicle types and let $V = [V_a, a \epsilon A_u]$ be the vector of selling prices for these vehicles [selling prices here are identified with the Red Book statistics (9)]. Let $B_a(V)$ be aggregate household purchases of vehicles of type a under prices V, let $W_a(V)$ be aggregate scrappage, and let $S_a(V)$ be aggregate sales. Also let X_a be the exogenous number of vehicles supplied by organizations to the household sector. Then the vehicle market can be said to be in (temporary) equilibrium when V is such that the conditions

$$B_a(V) + W_a(V) = S_a(V) + X_a \quad a \epsilon A_u \tag{2}$$

are jointly satisfied.

With approximately 600 distinct makes, models, and vintages delineated by our vehicle-holdings model, solution of a set of 600 nonlinear equations is required to determine a market equilibrium. In the forecasting context, where each prediction exercise involves a sequence of yearly market periods, this task clearly poses an unacceptable burden.

What is feasible, on the other hand, is to impose a relatively small subset of equilibrium conditions. That is, we may impose only the conditions

$$\sum_{a \epsilon A_{ud}} B_a(V) + W_a(V) = \sum_{a \epsilon A_{ud}} S_a(V) + X_a \quad d \epsilon D \tag{3}$$

where A_{ud}, $d \epsilon D$ is a collection of subsets of A_u. Through judicious selection of the subsets A_{ud}, the most-important features of equilibrium might be preserved through a relatively small set of such conditions. The extreme nontrivial case, of course, is to impose only the aggregate demand-equals-supply condition:

$$\sum_{a \epsilon A_u} B_a(V) + W_a(V) = \sum_{a \epsilon A_u} S_a(V) + X_a \tag{4}$$

If this is done, the problem of solving a system of

600 nonlinear equations is reduced to that of solving a single such equation.

When Equations 1-3 constitute a proper subset of the equilibrium conditions, multiple price vectors (V) will exist that solve these equations. To resolve this nonuniqueness, side constraints on V may be imposed. Assume that for each $a \epsilon A_u$, $V_a = f(X_a, \gamma)$ where f is a specified function of observed vehicle attributes X_a and of the free parameter vector γ of length $|D|$. In conventional jargon, $F(X, \gamma)$ is a hedonic price index. Given sufficient regularity in the equation system, an at least locally unique solution γ^* to Equations 1-3 will now exist. A particularly simple version of this approach, appropriate when the subsets A_{ud}, $d \epsilon D$ are mutually exclusive and exhaustive, is to set $V_a = X_a + \gamma_{d(a)}$, where X and γ are now scalars. Here, X_a is a benchmark price for vehicle a and $\gamma_{d(a)}$ is a shift factor that moves the prices of all used vehicles in the same class as a uniformly relative to those of new vehicles. Conditions of this kind are imposed in our forecasting system.

The major components and linkages of the model of the motor vehicle market are shown schematically in Figure 1. The figure depicts, for a single year, the process that generates purchase of new vehicles, transfers of used vehicles among households, and used-vehicle scrappage.

FORECASTS OF HOUSEHOLD MOTOR VEHICLE HOLDINGS

A forecast may be made with a model as complex as ours only if a simulation approach is adopted. The simulation system developed for use in this study operates on a sample of 1063 households from the 1976 Survey Research Center panel weighted so as to represent the U.S. household population. Preliminary tests of the sensitivity of the simulation to random number seed indicated excessive variability of results with this sample size. We, therefore, cloned each household into a pair of households that share all demographic attributes but whose random numbers are drawn independently. This procedure effectively doubled the sample size to 2126 and reduced the seed sensitivity to acceptable levels.

The Forecasting System

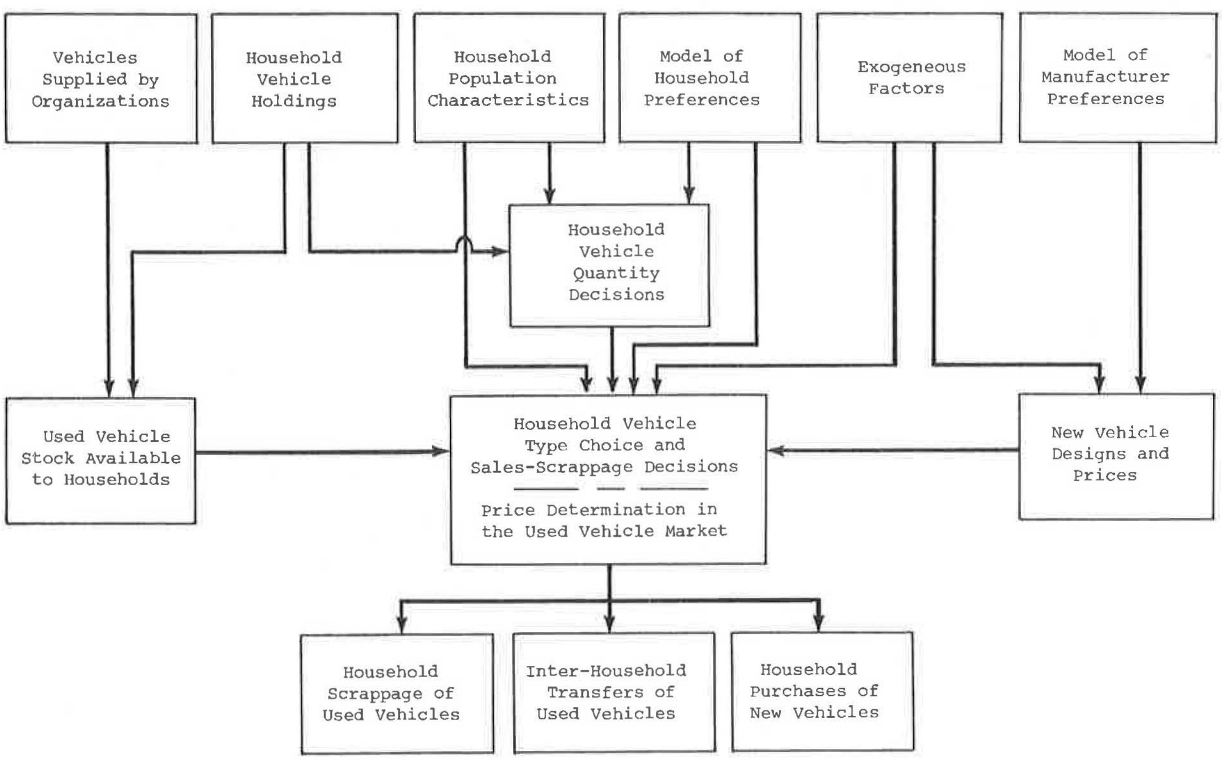
The first step in a given year's simulation is to apply the vehicle quantity model to predict the number of vehicles each household in the sample will own. Given any set of vehicle prices, the vehicle choice model then predicts the composition of holdings for each household. The scrap-sell model determines the manner in which vehicles are disposed. The final step in the year's simulation is, therefore, to search for a set of vehicle prices that generates desired holdings, sales, and scrappage that solve a practical set of equilibrium conditions.

At present, four equilibrium conditions are imposed. These are that household purchases plus scrappage should equal household plus organization vehicle sales for each of the following classes of vehicles:

1. Used passenger automobiles less than 10 years old,
2. Used passenger automobiles 10 or more years old,
3. Light trucks (pickup trucks, vans, and utility vehicles) less than 10 years old, and
4. Light trucks 10 or more years old.

The side constraints are that, within every class, the price of each vehicle type be the sum of two terms. One of these is an exogenously given base price for the type, computed as price when new minus an age-specific depreciation amount. The other is an endogenous shift factor common to all vehicles in the class. Under this specification, solution of the equilibrium conditions requires determination of

Figure 1. Model of the household motor vehicle market.



equilibrium values for the four shift factors.

The decision to impose these equilibrium conditions was made after experimentation with other options, including the simple setup in which only the aggregate condition (Equation 4) is imposed. It was found that the conditions and side constraints ultimately chosen consistently produced results in which demands were acceptably close to supplies when vehicles were categorized by vintage, size class, and other criteria. At the same time, the computational costs of solving the set of four conditions were reasonable. The algorithm used generally finds a set of equilibrium shift factors within three to four iterations. We note that, in general, uniqueness of the equilibrium is not theoretically guaranteed. However, uniqueness can be proved in the case when only the single condition (Equation 4) is imposed.

New-Vehicle Design and Price Projections

Available evidence indicates that, during the next several years, domestically produced passenger automobiles will weigh less, have less interior space, and have smaller engines than those now being produced. Some of the projected weight reduction will be achieved by material substitution and some will follow from a continuation of the "downsizing" trend begun in 1977. Downsizing is the attempt to reduce the dimensions of a vehicle with as little as possible accompanying loss of interior space. It is expected that, as vehicle weights are lowered, engine sizes will be reduced so that acceleration is left roughly constant but fuel efficiency is increased.

The primary impetus for the rather dramatic expected changes in domestic vehicle designs comes from the federal fuel-economy standards mentioned earlier. Penalties for noncompliance are substantial--a non-tax-deductible $5/vehicle for each 0.1 gal/mile below the standard. Since the sales-weighted mean fuel efficiency of 1978 domestic models was only 20.5 miles/gal but the standards call for 27.5 miles/gal by 1985, the need for design changes is clear. Foreign manufacturers, on the other hand, by and large meet the 1985 standards already. Relatively little change is expected in the designs of their vehicles. Likewise, we assume only a small modification in pickup truck, van, and utility-vehicle designs. Token weight reductions and minor reductions in engine size were assumed for these vehicles.

Within the forecasting system, the projected vehicle designs for each future year are represented as revisions to the designs of a base year, taken here to be 1978. Based primarily on material in a Corporate Tech Planning, Inc., report (10), a most-probable scenario for the extent and timing of the weight changes to be made by the domestic manufacturers of passenger automobiles has been formulated. With each projected weight change, there are associated projected changes in seating capacity, luggage space, and fuel efficiency for each affected base-year vehicle. Other attributes of the affected vehicles as well as all attributes of unaffected vehicles are held constant at their 1978 values.

In addition to vehicle designs, we must predict the prices of new vehicles. Consideration of the cost consequences of projected design changes suggests a 2 percent/year real increase in the prices of domestic automobiles. The projected rise reflects cost increases due to materials substitution and retooling as partially balanced by cost decreases from reductions in vehicle size. The prices of foreign automobiles and light-duty trucks are predicted to remain at 1978 levels in real terms.

The design-price scenario just set out is, of course, only a point prediction of events about which considerable uncertainty exists. The scenario discounts the possibility of fuel-saving technological advances in engine design and of cost-saving advances in the use of light body materials. We also ignore possible manufacturer manipulation of vehicle prices as an instrument for affecting the fraction of sales that goes to relatively fuel-efficient vehicles. It should be emphasized that our forecasting system can represent a wide range of design-pricing scenarios. Exploration of the sensitivity of the forecasts to variations in the scenario constitutes an important direction for future work.

Forecasts

In this section we present forecasts of household vehicle holdings, new-vehicle sales, used-vehicle scrappage, and vehicle fuel efficiencies through 1985. We have produced forecasts under two different assumptions about fuel prices:

1. Prices will remain at the level of $1.00/gal in 1979 dollars throughout the forecast period and
2. Prices will rise in equal yearly increments from $1.00/gal in 1980 to $2.50/gal in 1985, again in 1979 dollars.

The performance of forecasts under two such different assumptions serves two purposes. First, the spread from $1.00 to $2.50 brackets a reasonable range of values for a quantity about which considerable uncertainty exists. Second, with two values of fuel price, we can execute a useful controlled experiment in forecasting. As will be seen, the comparison of forecasts made under different assumptions about fuel prices while all other inputs are held constant reveals much about the structure of the forecasting system and, more importantly, about subtleties in the operation of the real motor vehicle market.

The first step in the forecasting process is to predict household vehicle-ownership levels for each of the sample households. The prediction is that total vehicle holdings will rise from 118.6 million in 1979 to 132.5 million in 1985. During this period the number of households is predicted to rise from 78 million to 87 million, which implies that the number of vehicles per household will remain stable at 1.52.

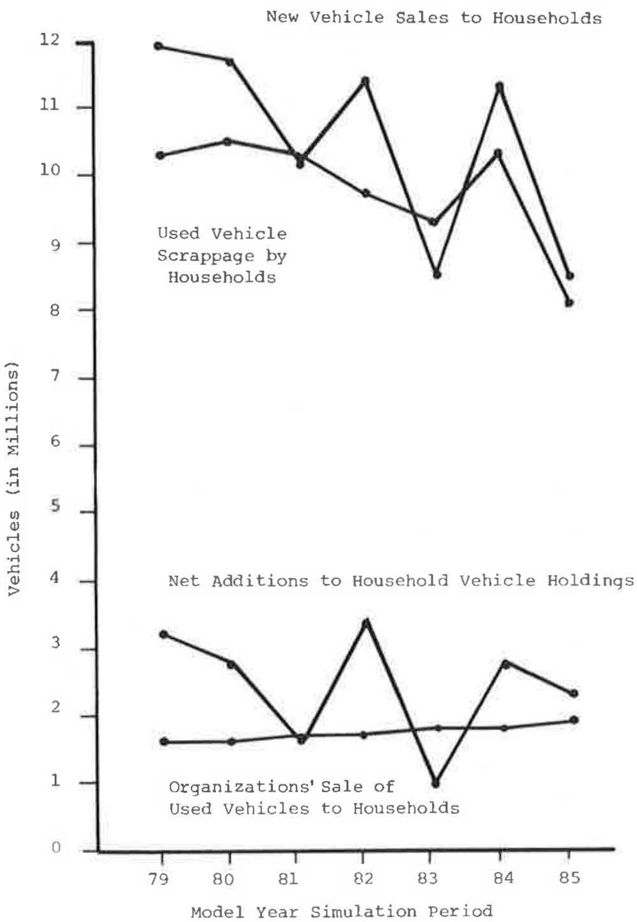
In predicting vehicle-holding levels each year, we also determine net additions to holdings, the path of which is shown in Figure 2. The makeup of net additions is, however, not yet determined. Net additions satisfy the identity

$$\Delta H \equiv \sum_{a\in A_n} S_a(V) - \sum_{a\in A_u} W_a(V) + \sum_{a\in A_u} X_a \qquad (5)$$

where ΔH designates net additions and A_n is the set of new-vehicle offerings. If we hold as fixed the exogenous contribution ΣX_a of organization-supplied vehicles, a given quantity of net additions is compatible with a combination of high new-vehicle sales (ΣS_a) and high used-vehicle scrappage (ΣW_a) or with a low sales-scrappage mix.

The combination of new-vehicle sales and used-vehicle scrappage that produces the required net additions is determined by the characteristics of new- and used-vehicle offerings and by the condition that the used-vehicle market be in equilibrium. To visualize the process, consider a situation in which new-vehicle offerings are found to be relatively desirable by households. In this case, the equilibrium prices of used vehicles will be relatively low, equilibrium scrappage relatively high,

Figure 2. Composition of net additions to household vehicle holdings.



and equilibrium new-vehicle sales high. On the contrary, a situation in which new vehicles are not liked but all other things remain the same leads to an equilibrium characterized by high used-vehicle prices, low scrappage, and low new-vehicle sales.

Figure 2 gives our point prediction for the sales-scrappage composition of net additions under the lower-bound assumption that gasoline prices remain at the $1/gal level through 1985. A striking finding is that new-vehicle sales tend to decrease over the period and fall from a high of 11.9 million units in 1979 to a low of 8.5 million in 1985. At the same time, scrappage declines from 10.3 million units at the beginning of the period to 8.1 million at the end. As a consequence, the age of vehicle holdings tends to increase. Our results indicate that, in 1979, 52 percent of all vehicles are at least five years old, and in 1985 the corresponding figure is 62 percent.

The trends our forecasts indicate for new-vehicle sales and scrappage are not monotonic, but the downward tendency is nonetheless unmistakable. Qualitatively, the movements in new-vehicle sales closely track those in net additions. The definite negative correlation in sales in adjacent years may also have a structural explanation. High new-vehicle sales one year accompanied by high scrappage implies that the age distribution of used vehicles will be more skewed toward young vehicles the next year. The result is lower scrappage and sales in the next year.

The most straightforward explanation for the series of findings is that, when the price of gasoline is $1/gal, households do not find the increased fuel efficiency of the new vehicles to be offered in the coming years worth the reduction in dimensions and increases in prices associated with downsizing. In this context, the prices of the larger inefficient vehicles produced up to the late 1970s are bid up with an attendant fall in scrappage and in new-vehicle sales relative to the levels that have prevailed recently. Note that this forecast rests in part on the interpretation of weight in the vehicle choice model. To some extent, weight proxies for comfort, ride quality, and safety. It is probable that impending changes in vehicle design will reduce vehicle weights without proportional decreases in these underlying consumer concerns. To the extent that this is true, our model will overpredict adverse consumer reaction to reductions in vehicle weight.

The above results have the interesting consequence that sales of new, more-efficient vehicles can be stimulated by increases in gasoline prices. Simply put, the higher gasoline prices are, the more attractive the new vehicles appear relative to older, less-efficient ones; hence, the lower are equilibrium used-vehicle prices, the higher is scrappage, and the higher are new-vehicle sales. The quantitative impact of gasoline prices on sales is shown well in our forecasts made under the upper-bound assumption that gasoline price rises in equal yearly increments from $1.00/gal in 1980 to $2.50/gal in 1985. In this scenario, new-vehicle sales for the years 1981-1985 are 10.5, 12.0, 9.3, 12.2, and 9.8 million units. These figures are 0.3, 0.6, 0.8, 1.0, and 1.4 million units higher than those shown in Figure 2.

Some caveats are required here. Our forecast that in 1985 a $2.50/gal gasoline price generates 1.4 million more units sold than does a $1.00/gal price ignores the effect of such a large price increase on the consumer's budget problem at the micro level and on economic activity at the macro level. Although the macro effects of the price increases are difficult to predict, the micro effect probably is to reduce total desired holdings of vehicles, with consequences for new-vehicle sales and used-vehicle scrappage. Possible limitations of demand for fuel-efficient vehicles due to considerations of production capacity are also ignored.

Figure 3 presents predictions of sales-weighted harmonic mean fuel efficiencies in units of miles per gallon. The harmonic mean is appropriate for calculations of fuel consumption because federal fuel standards are stated in these terms. The sales-weighted harmonic mean efficiency of vehicles in a class A_d is defined to be

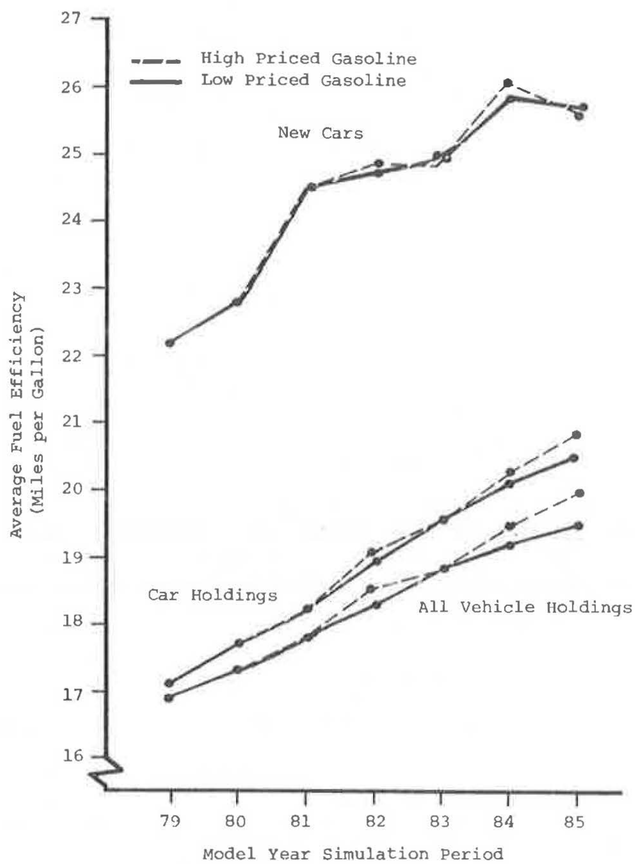
$$\bar{E}_d = \sum_{j \in A_d} N_j / \sum_{j \in A_d} (N_j/E_j) \tag{6}$$

where N_j is the number of units sold of vehicle type j and E_j is its efficiency in miles per gallon.

The qualitative features of the predictions are easy to interpret. All of the curves slope upward over time because the fuel efficiency of new vehicles improves with time and households purchase the new, more-efficient vehicles. This same fact explains why the efficiencies of vehicle holdings lag behind those of new vehicles. The curves for new-car efficiency lie above those for all new vehicles because the latter includes the fuel-inefficient light-truck vehicle class.

Observe that the average efficiency of new vehicles and of vehicle holdings are higher under the $2.50/gal gasoline price schedule than under the $1.00/gal scenario. On the other hand, car efficiencies are not significantly affected by an increase in fuel prices. Examination of the detailed forecasting results reveals the source of this seem-

Figure 3. Average vehicle fuel efficiencies.



ingly counterintuitive finding. That is, when fuel costs rise, there is a small shift in new-vehicle sales from the larger, less-efficient automobiles to the smaller, more-efficient ones but a much more substantial shift from the very inefficient light trucks to the only moderately efficient intermediate-sized automobiles. It is, in principle, possible for the average fuel efficiency of all vehicles to rise, yet for the efficiency of cars to fall. In particular, this would happen if the increase in fuel prices caused owners of light trucks to switch to full-sized cars in sufficient numbers.

It is of interest to ask whether automobile manufacturers will meet the federal fuel-economy standards if they make the design and pricing changes assumed in our scenario. The standards call for each manufacturer to achieve sales-weighted harmonic average efficiencies of 19, 20, 22, 24, 26, 27, and 27.5 miles/gal in 1979-1985, respectively. Our point predictions for the average efficiencies of all new cars are 22.2, 22.8, 24.5, 24.7, 24.9, 25.9, and 25.7 miles/gal in the $1.00/gal gasoline price case and almost identical figures in the $2.50/gal case. Thus, in the aggregate, the standards are not met from 1983 on.

The aggregate figures do not, however, tell the full fuel-efficiency story. More disaggregated forecasts indicate that, in the later years of the period, domestic manufacturers generally approach and, in some cases, surpass the standards. On the other hand, foreign manufacturers experience a drop in average fuel efficiencies over time and therefore fail the standards by increasing amounts. This seemingly perverse result has a straightforward explanation. As time passes, the assumed constant real costs of imports make them increasingly a bargain relative to domestic cars. In particular, the larger, relatively fuel-inefficient imported models that compete with the larger domestic cars are forecast to increase in sales substantially. Sales of small imports also increase, but to a lesser degree. Hence, in toto, import sales shift to a less-efficient mix of vehicles.

In interpreting these results, two caveats must be made. First, it is unlikely that foreign or domestic manufacturers would maintain our projected design strategies if it became clear that their resulting sales mixes were falling below mandated standards. Thus, the forecasts should not be interpreted as a statement that selected manufacturers cannot meet federal fuel-economy standards in an absolute sense, but only that design-price strategies that differ from those currently envisioned may have to be employed.

The second caveat is that our predictions about fuel economy exclude new-vehicle sales to organizations. These sales have been estimated to constitute up to 20 percent of total sales. To the extent that fleet sales are skewed toward larger or smaller vehicles than those purchased by households, our fuel-economy estimates will be biased upward or downward.

To close this discussion, let us emphasize that, although the federal fuel-economy standards apply to new vehicles, the national concern is with the fuel efficiency of all vehicle holdings. Our forecasts indicate that, in each year through 1985, the average efficiency of holdings will lag behind that of new vehicles by 3.5-4.0 miles/gal. In the absence of further increases in the efficiencies of the new vehicles offered after 1985, it is likely that holdings will not reach the efficiency of new 1985 vehicles until sometime in the mid-1990s.

CONCLUDING REMARKS

How accurate are the forecasts presented here? Our view is that it is important to distinguish between the reasonableness of our point-estimate forecasts and the ultimate usefulness of the model system for policy analysis. From both these perspectives, our results can be interpreted on several levels.

On the most benign level, even if one accepts the market structure as represented in our model, the specifics of our forecast scenario assumptions are open to question. In developing the forecasting system, our primary concern was with ensuring that the models were fully sensitive to policy--to manufacturer design strategies, to demographic influences, and to government policies that affect vehicle prices or fuel efficiencies. Two scenarios were evaluated and reported on here. Are they realistic? Probably not. As was noted earlier in the paper, manufacturers will undoubtedly develop their design-price strategies in an evolutionary manner, cognizant of year-by-year market transactions. This element of conditional decision making was beyond our research scope, but clearly not beyond the capabilities of the model system. Indeed, our simulation approach is designed to operate on a year-by-year basis, and outcomes in any year depend strongly on previous year's sales and holdings. What the actual most likely scenario will be is a difficult question, since the future depends on the outcomes in a complex market where numerous manufacturers develop strategies in secret. Our model can only respond to the question, What if the motor vehicle market were defined in our scenario?

In view of the above, our fuel-efficiency forecasts, for example, must not be interpreted as an absolute statement that selected manufacturers will not meet mandated 1985 fuel-economy standards. The results reported here are really just a starting point for consideration of the impacts of alternative government policy and manufacturer strategies aimed toward improving vehicle fuel efficiency.

A major distinction between our disaggregate approach and the numerous aggregate approaches applied to vehicle forecasting is that the latter's explanation of new-vehicle sales through stock-adjustment equations does not capture the joint endogeneity of new-vehicle sales, used-vehicle scrappage, and used-vehicle prices. Our forecasting system, although simplified for computational application, certainly provides a more realistic representation of the operation of the vehicle market.

In summary, our initial research on developing and applying a disaggregate modeling approach to forecasting future motor-vehicle sales and holdings has proved highly encouraging. Our results are really the beginning of an ongoing need to analyze and monitor the motor vehicle market through the 1980s. We have applied our modeling approach to just two future scenarios.

Additional forecasts are called for as manufacturers' strategies evolve. With an eye toward improvement of our models, future work should seek to further illuminate the linkages that connect household behavior in choosing motor vehicles and other vehicle-related decisions. In particular, a joint analysis of ownership level, the composition of holdings, and vehicle use would be a valuable contribution.

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Transportation System Management Actions: A Study of the Energy Costs

GERALD S. COHEN

Transportation system management (TSM) actions often save energy, primarily through diversion. They also incur energy costs of construction, maintenance, and operation. This paper examines the magnitude of such costs. Selected TSM actions that are scheduled for implementation in New York State are examined to determine the aspects of the projects that generate energy costs. Appropriate energy factors (equivalent gallons of gasoline per dollar of project cost) are given for many types of actions and there is a brief discussion of procedures for determining these factors. Estimates are provided for the cost of typical TSM projects. On the average, energy costs represent approximately 15 percent of energy savings. Actions such as encouragement of ridesharing have the smallest energy costs, and actions that result in additional transit vehicle miles of travel have the largest.

The federal government requires transportation system management (TSM) actions to be a component of urban transportation plans. These actions are intended to increase the capacity and efficiency of the existing transportation system by improving traffic flow, smoothing out peak-period loads, and diverting drivers to high-occupancy modes of travel. General categories of TSM actions include the following:

1. Actions to ensure efficient use of road space,
2. Actions to reduce vehicle use in congested areas,
3. Actions to improve public transit service, and
4. Actions to improve transit management efficiency.

Such actions can often reduce vehicle miles of travel (VMT) and increase vehicle speeds in con-