THE DEMAND FOR PASSENGER CAR TRANSPORT SERVICES AND FOR GASOLINE

By Ali M. Reza* and Michael H. Spiro†

I. INTRODUCTION

This paper reports some findings on the demand for passenger car transport services and on gasoline consumption. A model is developed describing the demand for passenger cars, for miles travelled and for attributes of passenger cars, which in this paper are measured by the average weight of cars. The propositions derived from this model and the estimated equations enable us to estimate the demand for gasoline. On the basis of these results, we are able to determine the short-run and long-run effects of changes in the price of gasoline on miles travelled and, hence, on gasoline consumption. The short-run effect of a change in the price of gasoline on gasoline consumption results only from a change in miles travelled by the existing stock of cars; the long-run effect results from a combination of changes in miles travelled, the size of the stock of cars, and the composition (in terms of efficiency) of the stock of cars.

This work goes further than previous writings in several ways. First, recent published studies attempting to measure gasoline demand employ a first-order distributed lag model with income, price of gasoline, and lagged consumption of gasoline as explanatory variables.1 It is demonstrated here that demand for gasoline is determined by, among other variables, the stock of cars, the overall efficiency of the stock, and the utilisation rate of that stock. The approach followed here allows us to measure these separate effects. Second, Houthakker, Verleger and Sheehan (1974) suggest (page 413) that “It would be better to incorporate the utilisation of the stock (of cars) directly in the demand (for gasoline) equation and then derive a model which separates the utilisation (rate of cars) and the investment (in building up the stock of cars) . . . into two equations.” This suggestion is implemented in this study.

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† Graduate School of Business, University of Pittsburgh. We are indebted to our colleagues Josephine Olson, Michael Landsberger, James Craft, Edward Sussna, Mildred Myers, and Allen Zellenits for their suggestions. We are also grateful to Professor Daniel B. Suits of Michigan State University, Herbert T. Spiro of the California State University in Northridge, and Charles E. Phelps of the Rand Corporation, for comments on an earlier version. Finally, we wish to thank R. L. Polk and Company for sharing with us some of the data used in this study. John R. Gipkala and Thomas H. McInish provided valuable research assistance. An earlier version of this paper was presented at Western Economic Association meetings, Annahem, California, in June 1977.
1See, for example, Kennedy (1974) and Houthakker, Verleger, and Sheehan (1974).
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Third, this study includes the price of gasoline as an explanatory variable for the demand for new cars and, therefore, as a determinant of the steady state stock of cars.  

The propositions derived from this model are tested with quarterly data for the period 1969 I to 1976 III. The results of the empirical analysis support the model and can be useful in the formulation of public policy. For instance, the implications of a tax on gasoline, on automobiles or on the weight of automobiles, and of mandatory fuel efficiency requirements for gasoline consumption, can be estimated by this model. Although the econometric model presented here permits only the determination of the short-run and steady state responses, the model—when converted into a simulation model—permits the determination of the implications of such policies for any time horizon specified.

The paper is divided into four sections. Following this introduction, Section II contains the development of the model. Section III presents the results of the testing of the proposition derived in Section II. The response of gasoline consumption to gasoline price and other variables is estimated in Section IV. The data sources are described in detail in Appendix A, and Appendix B provides the proof of one of the results.

II. THE MODEL

As is customary, the consumer is assumed to maximise a utility function

\[ U = U(S, Z), \]  

where \( S \) represents the services automobiles yield and \( Z \) represents other goods. In turn, automobile services are generated according to

\[ S = S(K, M, L), \]  

where \( K \) denotes the number of cars the consumer (or the household) owns, \( M \) represents the number of miles driven by the consumer, and \( L \) represents the "quality" of the cars owned. The precise definition of quality and its measurement pose problems affecting our empirical results; but, for the moment, suffice it to say that these problems are not likely to affect the most important conclusions reached here.

The substitution of (2) into the utility function (1) and the maximisation of the resulting function subject to an appropriate income constraint, assuming that an interior solution exists, yields demand functions for the number of automobiles, the number of miles the consumer desires to drive, and the level of quality:

\[ K^* = K^*(Y, P_K, P_M, P_L) \]
\[ M^* = M^*(Y, P_K, P_M, P_L) \]
\[ L^* = L^*(Y, P_K, P_M, P_L). \]  

In an unpublished paper which was brought to our attention after this study was completed, Sweeney included the cost of operating a car in the demand for new cars, but the coefficient of this variable is statistically insignificant. See Sweeney (undated), Table 2, p. 29.
In (3), $Y$ represents disposable per capita income and $P_K$, $P_M$, and $P_L$ denote the (appropriately defined) prices of $K$, $M$, and $L$, respectively. In expressing the functions (3), we have assumed demand functions to be homogeneous of degree zero in income and prices; accordingly, as we have used the price of other goods as numeraire, the arguments in the functions (3) are all in real terms.

An issue in which we are interested, and one which is of concern to national policy, is the determination of the quantity of gasoline used during a given period of time. In the context of our analysis, demand for gasoline by consumers is derived from their demand for miles to drive. If we let $G$ represent the quantity of gasoline a consumer demands, then

$$G = \frac{M}{E},$$

where $E$ measures the number of miles a car can be driven on one gallon of gasoline (that is, $E$ measures miles per gallon). Thus, gasoline consumption varies not only through $M$ because of variations in income and in the prices $P_j (j = K, M, L)$, but also because of variations in the efficiency $E$ of the existing stock of cars; thus, knowledge both of the function $M^*$ and of the efficiency of the existing stock of cars is necessary for the determination of the quantity of gasoline consumed—a point not adequately dealt with in previous studies.

In order to measure the prices $P_j$ for an empirical study, one should define them precisely; to this task we now turn. $P_M$ measures the cost of driving a unit distance; it should therefore include costs directly associated with operating a car. Since the cost of gasoline constitutes the main component of the cost of driving, it is taken to represent all other costs related to the operation of the automobile. $^3$ Hence, $P_M$ is the price of gasoline ($P_G$) adjusted by the efficiency of cars ($E$); that is,

$$P_M = \frac{P_G}{E}.$$  \hspace{1cm} (5)

Together, (4) and (5) permit us to obtain the relationship between the elasticity of gasoline consumption with respect to efficiency—$\eta(G, E)$—and the elasticity of gasoline consumption with respect to the price of gasoline—$\eta(G, P_G)$:

$$\eta(G, E) + \eta(G, P_G) = -1, \text{ for all } M.$$  \hspace{1cm} (6)

Note that the relationship between the two elasticities can be obtained only if the demand for gasoline is properly determined, as in (4), and the cost of driving is appropriately defined, as in (5).

$P_K$ measures the user-cost of a "standard" automobile, that is, a car whose quality has remained constant over time. Since the automobile is a durable good which yields services over a number of years, from the consumer's point of view there is an opportunity cost associated with keeping a car, as reflected by its depreciation and by foregone interest earnings. Thus the relevant variable for analysis is the user-cost of the car, namely,

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$^3$Sweeney (undated) experimented with the value of time as an additional component of cost of driving, but found that cost of gasoline alone was empirically a better variable, since in all the experiments it was statistically more significant than the cost variable containing an estimate of the value of time.

$^4$The proof of (6) is presented in Appendix B.

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where $P_C$ is the price of the standard car, $\delta$ is the rate at which it depreciates, and $r$ is the rate of interest.

Similarly, $P_{L,t}$ measures the user-cost of quality, $P_{L,t} = P_Q(\delta_t^* + r)$, where $P_Q$ is the purchase price of quality and $\delta_t^*$ is the rate of depreciation of quality.

For empirical analysis, demand functions (3) need to be approximated by explicitly-specified functions. We experimented with the linear and log-linear specifications, but the empirical results were virtually identical in the signs and significance of coefficients, the explanatory power of the equations, and the estimated elasticities; for this reason, only the results obtained with the linear approximation will be presented here. The demand functions (3) are approximated by:

$$K_t^* = a_1 + b_1 Y_t + c_1 P_{K,t} + d_1 P_{M,t} + e_1 P_{L,t},$$

$$M_t^* = a_2 + b_2 Y_t + c_2 P_{K,t} + d_2 P_{M,t} + e_2 P_{L,t},$$

$$L_t^* = a_3 + b_3 Y_t + c_3 P_{K,t} + d_3 P_{M,t} + e_3 P_{L,t}.$$ (8)
(9)
(10)

It is expected that an increase in income will result in an increase in the stock of cars, in miles travelled, and in the quality of cars; that is, $b_1 > 0$. An increase in the user cost of cars, cost of driving, and cost of quality will result in a decline in the stock of cars, in miles travelled and in the quality of cars; that is, $c_t < 0$, $d_t < 0$, and $e_t < 0$. These functions are applicable when the system achieves its long-run equilibrium state. The remainder of this section is devoted to their modification in order to develop a short-run model amenable to estimation.

There is ample evidence to suggest that the actual stock of durable goods may diverge in the short run from the optimal; recent automobile demand studies (Juster and Wachtel (1972) and Mishkin (1976)) reinforce the hypothesis that actual stock of cars is only slowly adjusted to the optimal level. As we are using linear functions to approximate the demand functions (3), we postulate the stock adjustment process

$$K_t - K_{t-1} = \lambda (K_t^* - K_{t-1}), \quad 1 \geq \lambda \geq 0,$$ (11)

where $\lambda$ measures the speed with which the actual stock of cars, $K_t$, is adjusted to the optimal level, $K_t^*$.

The actual stock at time $t$ is related to past stocks according to

$$K_t = R_t + (1 - \delta)K_{t-1},$$ (12)

where $R_t$ is the number of new cars added to the existing stock. Substituting (11) and (8) into (12) yields

$$R_t = \lambda K_t^* - (\lambda - \delta)K_{t-1}$$

$$= \lambda (a_1 + b_1 Y_t + c_1 P_{K,t} + d_1 P_{M,t} + e_1 P_{L,t}) - (\lambda - \delta)K_{t-1},$$ (13)

which is the equation used to estimate the demand for new cars. Since the rate of depreciation, $\delta$, is calculated from the data according to equation (12), the parameter, $\lambda$, can be evaluated and the remaining parameters can be computed.
An implication of the specification (13) is that expectations, in the context of the adaptive expectations hypothesis, are formed instantaneously; this is so because a two-period lagged stock variable \((k_{t-2})\) is absent from equation (13).\(^5\) We did consider the possibility that expectations were formed more slowly (in the context of a quarterly model), but the empirical results did not support that possibility.

In the short run, the stock of cars, \(K\), and their average quality, \(L\), are fixed, so that transport services (and, hence, utility) can vary only as a result of changes in miles driven, \(M\). Accordingly, the costs associated with \(K\) and \(L\)—namely, \(KP_K\) and \(LP_L\)—are also fixed. The short-run mileage relationship, approximated by a linear function, can therefore be written as

\[
M_t = a_4 + b_4(Y_t - \bar{K}_tP_{K,t} - \bar{L}_tP_{L,t}) + \epsilon_4P_{M,t} + d_4\bar{K}_t + \epsilon_4\bar{L}_t,
\]

where \(\bar{K}\) and \(\bar{L}\) are constant in the short run.\(^6\)

With respect to quality determination we restricted our attention to new cars; therefore, the adjustment process in this case is instantaneous and the model (10) need not be modified.

The results of the testing of the propositions implied by this model are presented in the next section.

### III. EVIDENCE OF THE DEMAND FOR TRANSPORT SERVICES

The regression results, obtained on the basis of seasonally adjusted quarterly data covering the period 1969 I to 1976 III, appear in Table 1.

Two sets of equations are presented in Table 1; the set with postscript \(a\) differs from the set with postscript \(b\) in that in the latter set the price of gasoline, \(P_G\), is substituted for the cost of driving. The reason for considering the second set of specifications will be discussed later.

A number of issues pertaining to the estimation technique, sources and nature of data, and the construction of certain variables need to be considered before the empirical results are discussed.

The least squares results led us to conclude that serial correlation may be sufficiently serious to distort the empirical results; the empirical results reported in Table 1 are those obtained by the iterative technique of purging serial correlation suggested by Cochrane and Orcutt (1949).

The detailed description of the nature and sources of data is presented in Appendix A. Suffice it to say here that many of the data were obtained from official government publications (income and prices), and some were obtained from trade publications and commercial data collection organizations; these, incidentally, are also the sources of much of the government data (registrations by automobile class, stock of

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\(^5\)For more detail on this, the reader is referred to Juster and Wachter (1972).

\(^6\)The function (14) is obtained when \(U[\bar{z}, S(\bar{K}, M, \bar{L})]\) is maximised with respect to \(\bar{z}\) and \(M\), subject to the income constraint \(Y - \bar{K}\Pi_X - \bar{L}\Pi_L = \bar{z}\Pi_Z + M\Pi_M\), where \(Y\) and the \(\Pi\)'s represent nominal income and nominal prices, respectively. \(\Pi_Z\) is then used as numeraire in order to express demand for miles as a function of real income \(Y\) and relative prices \(P_i\)'s.
Table 1

Regression Results

<table>
<thead>
<tr>
<th>Explanatory Variables</th>
<th>New Car Registration, R Equation</th>
<th>Miles Driven, M Equation</th>
<th>Weight of New Cars, L Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(13a)</td>
<td>(13b)</td>
<td>(14a)</td>
<td>(14b)</td>
</tr>
<tr>
<td>Constant</td>
<td>55.80</td>
<td>-42.09</td>
<td>-51.06</td>
</tr>
<tr>
<td></td>
<td>(5.09)</td>
<td>(2.62)</td>
<td>(2.87)</td>
</tr>
<tr>
<td>$Y$</td>
<td>10.29</td>
<td>7.58</td>
<td>8.03</td>
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<tr>
<td></td>
<td>(3.08)</td>
<td>(3.24)</td>
<td>(3.37)</td>
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<td>$P_K$</td>
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<td>-232.60</td>
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<tr>
<td></td>
<td>(4.96)</td>
<td>(5.07)</td>
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<td>$P_M$</td>
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<td>(2.90)</td>
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</tr>
<tr>
<td></td>
<td>(3.17)</td>
<td>(3.46)</td>
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<td>$K_{-1}$</td>
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<td>0.0871</td>
<td>0.0895</td>
</tr>
<tr>
<td></td>
<td>(4.95)</td>
<td>(4.77)</td>
<td></td>
</tr>
<tr>
<td>$L_{-1}$</td>
<td>0.0085</td>
<td>0.0103</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1.73)</td>
<td>(1.93)</td>
<td></td>
</tr>
<tr>
<td>$X$</td>
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<td>-0.996</td>
<td>-1.012</td>
</tr>
<tr>
<td></td>
<td>(3.96)</td>
<td>(2.60)</td>
<td>(2.58)</td>
</tr>
<tr>
<td>$T$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.82</td>
<td>0.98</td>
<td></td>
</tr>
<tr>
<td>$DW$</td>
<td>1.98</td>
<td>1.98</td>
<td></td>
</tr>
<tr>
<td>$\rho$</td>
<td>-0.369</td>
<td>-0.382</td>
<td></td>
</tr>
</tbody>
</table>

The absolute values of t-ratios are shown in parentheses. $\rho$ is the estimate of the coefficient of first-order serial correlation.

Equations a are based on the cost of driving, equations b on the cost of gasoline.

cars, and attributes of new cars). Some variables we had to construct ourselves because the needed data do not exist (quarterly figures on the gasoline efficiency of the stock of cars, and miles travelled by passenger cars). We were unable to obtain or construct data for price of quality, and the likely implications of the omission of this variable are discussed below.

The dummy variable $X$ is included in order to account for the effect of the oil embargo of late 1973 and early 1974.

The weight of a car is used as a proxy for its quality. The justification for this is that most of the characteristics consumers seem to associate with quality tend to affect the weight of the car (e.g., roominess, air conditioning, radio, powered brakes,
etc., all adding to the weight of the car).\textsuperscript{7} Automobile manufacturers have been attempting to reduce the weight of cars over the past several years; their attempt has been partially defeated as the result of the addition of safety features and devices for the control of pollution. We have hypothesised that these features and devices have just about cancelled out the weight reduction which otherwise would have been achieved on the 1969 through 1974 models, but that the weight reduction programme has become relatively more important after the 1973–74 oil embargo, so that the 1975 and 1976 models became successively less heavy (for any given level of quality). The dummy variable $T$ reflects this process.

The consequence of the omission of $P_L$ from the regression is, of course, the introduction of bias in the coefficients of some of the included variables. The variables whose coefficients are unlikely to be biased as a result of the omission of $P_L$ from the estimated equations are those of $Y$ and $K$; the absence of any significant correlation between $P_L$ with $Y$ and $K$ is sufficiently obvious on a priori grounds to render any discussion unnecessary.

The factors which affect the manufacturing and distribution costs of a standard car and of quality tend to be similar; a car and its quality are complementary, so that demand effects influence both similarly. For these reasons, it is expected that, except for occasional aberrations, $P_K$ and $P_L$ will move more or less in phase; thus, is is likely that a positive correlation exists between $P_K$ and $P_L$ and that, therefore, the estimate of the coefficient of $P_K$ is biased in an upward direction in absolute value.

Estimation of equation (14) requires the measurement of $LP_L$, for which the precise definition of quality and its measurement are needed (proxies or indices will not do). Since this seemed to be an insurmountable problem at this time, we had to delete the term $LP_L$ from the income measure in (14). Equation (14) was then estimated using two alternative measures of income: $Y$ and $Y - ar{K}P_K$. The regression results were virtually identical; this is to be expected, since $\bar{K}P_K$ is very small relative to $Y$ and the movements in $Y$ are more pronounced than those in $\bar{K}P_K$. The similarity in these results led us to use the equation with $Y$, since this avoids non-linearity in the long-run mileage equation (9).\textsuperscript{8}

Each equation was estimated using either the cost per mile of driving—$P_M$, reflecting the cost of driving the existing stock, or $P_M^R$, reflecting the cost of driving new cars—or the price of gasoline, $P_G$.\textsuperscript{9} In previous studies of gasoline consumption, $P_G$ (and not $P_M$) has been used as an explanatory variable. Since the propositions derived from the model presented here will be used to derive gasoline demand equations, we thought that it would be useful to present, in addition to the results which are obtained from the model, results based on an alternative set of hypotheses which use $P_G$ as an explanatory variable.

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\textsuperscript{7}Since we are interested in the determinants of gasoline consumption, the use of weight as a proxy for quality is particularly useful because in our experiments, using cross section data, we obtained an inverse relationship between weight and miles per gallon. These results can be obtained from the authors upon request. However, this negative relationship was not present in time series analysis, undoubtedly because of changes in the composition of the addition to the stock and technological changes.

\textsuperscript{8}The results of the equation with $Y - \bar{K}P_K$ are available from the authors upon request.

\textsuperscript{9}Justification for assuming $P_G$ to be exogenously determined can be found in Phelps and Smith (1977).
Overall, the empirical results support the model developed in this paper. Without exception, the coefficient estimates have the expected signs, and those of the new car registration and mileage equations are highly significant as well. The poorest performer is the weight equation.

Of particular interest in the new car registration equation is the result that operating costs, as measured by gasoline cost, do reduce sales of new cars and thus affect the optimal stock of cars.

The interesting aspect of the mileage equation is the result that the quality of a car apparently influences the number of miles it is driven: the more (less) "comfortable" the car is, the more (less) it will be driven. Thus, factors which affect the level of the quality of new cars (and hence of the stock) seem to affect travel and therefore gasoline consumption.

The statistical characteristics of the weight equation are weaker than those of the new car registration and mileage equations. The coefficient estimates are not as significant, but it should be mentioned that the coefficients of $T$ and $P_K$ are significant at better than the 90% level in a one-tailed test. Serial correlation is more serious and, of course, the predictive power of the equation is lower. These problems are due, at least in part, to the fact that "quality" is a complex concept and its definition, let alone its measurement, is very difficult, if not impossible; yet no better summary measure of quality than weight was obvious to us.

There is no significant difference between the results obtained with cost per mile of driving, and those obtained with price of gasoline, as explanatory variable. This is undoubtedly due to the rather limited variability in the efficiency of the stock during the period under study. However, since the set of equations with the cost per mile of driving is derived from the theoretical model, and since this set is richer in information content and policy implications than the set with price of gasoline only, it is being used in the remainder of this study.

The results of the analysis are summarised in Table 2, which contains the calculated short and long-run elasticities of the dependent variables with respect to the various independent variables. The long-run elasticities for miles travelled are calculated after substituting equation (13a) into equation (12), solving equation (12) for its steady state solution and substituting the expression for $K$ into equation (14a). The long-run elasticity estimates for steady state $K$ are based on equations (12) and (13a).

In examining these elasticities, it should be noted that new car registration is much more elastic than the stock of cars with respect to income and the price of cars. Furthermore, the long-run elasticity of miles travelled with respect to either price of gasoline or gasoline efficiency is higher than the short-run elasticity. This, of course, is due to the fact that, in the long run, the higher driving costs will not only affect miles travelled, but will also reduce the stock of cars, which, ceteris paribus, tends to decrease driving.

We end this section with Table 3, which contains the elasticities of new car purchases with respect to price and income as reported in other published studies. A comparison of the two tables (Tables 2 and 3) reveals that our estimate of income elasticity is in the range of those reported by the other investigators, while our estimate of price elasticity is somewhat larger than those reported but quite similar to the one reported by Wykoff (1973), which is the latest study in the sample. We were
### Table 2

**Elasticities of Transport Services**

<table>
<thead>
<tr>
<th>Elasticity of</th>
<th>With respect to</th>
<th>Short-run</th>
<th>Long-run</th>
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<tbody>
<tr>
<td>$R$</td>
<td>$Y$</td>
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</tr>
<tr>
<td></td>
<td>$P_a$</td>
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<td></td>
<td>$P_o$</td>
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</tr>
<tr>
<td></td>
<td>$E$</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>$K$</td>
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<td></td>
</tr>
<tr>
<td>$M$</td>
<td>$Y$</td>
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<tr>
<td></td>
<td>$P_s$</td>
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<td>-0.65</td>
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<tr>
<td></td>
<td>$P_o$</td>
<td>-0.21</td>
<td>-0.33</td>
</tr>
<tr>
<td></td>
<td>$E$</td>
<td>0.21</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>$K$</td>
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</tr>
<tr>
<td></td>
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</tr>
<tr>
<td>$L$</td>
<td>$Y$</td>
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<td></td>
<td>$P_s$</td>
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<td>$E^k$</td>
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<td>$Y$</td>
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<td>$P_s$</td>
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<tr>
<td></td>
<td>$E$</td>
<td>0.13</td>
<td></td>
</tr>
</tbody>
</table>

*n.s. indicates estimated coefficient not significant.

### Table 3

**Summary of New Car Purchase Elasticities for Automobiles as Reported in Other Studies**

<table>
<thead>
<tr>
<th>Study</th>
<th>Time Period</th>
<th>Price</th>
<th>Income</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wykoff*</td>
<td>1950–1970</td>
<td>-1.70</td>
<td>1.09</td>
</tr>
<tr>
<td>Hamburger*</td>
<td>1953–1964</td>
<td>-1.17</td>
<td>4.32</td>
</tr>
<tr>
<td>Suits*</td>
<td>1929–41, 1949–56</td>
<td>-1.20</td>
<td>3.90</td>
</tr>
<tr>
<td>Chow*</td>
<td>1920–41, 1948–53</td>
<td>-1.20</td>
<td>3.00</td>
</tr>
<tr>
<td>Atkinson*</td>
<td>1925–1940</td>
<td>-1.40</td>
<td>2.50</td>
</tr>
<tr>
<td>Roo and Von Szeliski*</td>
<td>1919–1937</td>
<td>-1.50</td>
<td>2.50</td>
</tr>
</tbody>
</table>

*From Table 1 in Wykoff (1973).
*From Table 2 in Hamburger (1967).
*From Table 3 in Hamburger (1967).
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unable to locate any published studies which incorporate measures of efficiency and weight, so we do not report comparative elasticities for the other variables.

Having completed the discussion of the results of the estimation of our model, we shall next address ourselves to demand for gasoline.

IV. DEMAND FOR GASOLINE

In this section we present the gasoline demand equation implied by our model. Upon substituting the equation describing the demand for miles travelled (equation (14a)) into the equation specifying the technological relationship between miles travelled, efficiency and gasoline consumption (equation (4)), equation (15) is derived:

\[
G_i = M_i/E_i \\
= (-42.09 + 7.58Y_i - 1.163P_{M,i} + 0.087K_{i-1} 
+ 0.0083L_i - 0.996X)/E_i. 
\]  

(15)

Equation (15) permits the estimation of the short-run response of gasoline consumption to, among other factors, increased efficiency. The response consists of two effects: first, increased efficiency has the same effect as a decline in gasoline prices, and induces more travel; second, the increased travel will require less fuel per unit of distance because of the higher efficiency. Thus, the reduction in gasoline consumption which results from higher efficiency of cars is partially offset by more miles travelled; and, depending on the magnitudes of each of the above effects, their combined effect could conceivably cause gasoline consumption to rise.\(^{10}\)

Equation (15), when combined with equations (14a) and (13), yields a steady state equation for the demand for gasoline, as follows:

\[
G = 23.99/E + 18.23Y/E - 6.77P_K/E - 1.84P_G/E^2, 
\]

(16)

where, of course, \(P_G/E^2 = P_M/E\).

The summary of the elasticities of gasoline consumption with respect to price and income is presented in Table 4, which also contains similar results from other studies. Our estimates of income elasticities are somewhat higher than those reported by Houthakker et al. (1970) but very similar to the ones reported by Kennedy (1974). Our estimates of price elasticities are higher than those reported by Houthakker but considerably lower than those reported by Kennedy. Since Kennedy also used Western European data in his sample and Houthakker et al. used earlier U.S. data, the differences are probably explainable by the differences in the prevailing prices of gasoline.

In addition, we present in Table 5 the elasticities of gasoline consumption with respect to efficiency, stock of cars, weight of cars and price of cars, for which we could not find comparable estimates in other published studies. Of particular interest are

\(^{10}\)This issue is also relevant for most appliances. Thus, for example, as room air-conditioners become more energy efficient, consumers may use them more intensively, thereby partially defeating the objective of reduced energy consumption.
Table 4

Gasoline Consumption Elasticities with Respect to Price and Income

<table>
<thead>
<tr>
<th>Study</th>
<th>Time Period</th>
<th>Price Elasticity</th>
<th>Income Elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>S Run</td>
<td>L Run</td>
</tr>
<tr>
<td>Reza-Spiro</td>
<td>1969–76</td>
<td>-0.210</td>
<td>-0.33</td>
</tr>
<tr>
<td>Houthakker (1974)</td>
<td>1963–72</td>
<td>-0.075</td>
<td>-0.24</td>
</tr>
<tr>
<td>Kennedy (1974)</td>
<td>1962–72</td>
<td>-0.465</td>
<td>-0.82</td>
</tr>
</tbody>
</table>

Table 5

Gasoline Consumption Elasticities with Respect to Price of Cars, Efficiency, Stock and Quality

<table>
<thead>
<tr>
<th>Elasticity of G with Respect to</th>
<th>Short-run</th>
<th>Long-run</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_k$</td>
<td>—</td>
<td>-0.65</td>
</tr>
<tr>
<td>$E$</td>
<td>-0.80</td>
<td>-0.76</td>
</tr>
<tr>
<td>$K$</td>
<td>0.94</td>
<td>—</td>
</tr>
<tr>
<td>$L$</td>
<td>0.76</td>
<td>—</td>
</tr>
</tbody>
</table>

the elasticities of $G$ with respect to $E$. This is the only case where the long-run elasticity is smaller, in absolute terms, than the short-run elasticity. The reason, of course, is that an increase in gasoline efficiency will not only result in more travel, but in the long run will also result in an increase in the stock of cars. The short-run elasticity, given current automotive technology, is of purely theoretical interest. However, the intermediate impact of increased fuel efficiency in new cars is of great interest for policy analysis and can be determined from this model through simulation exercises.

APPENDIX A

All the data are quarterly, seasonally adjusted, covering the period 1969 I to 1976 III. The dummy variable $X$ is included in order to account for the oil embargo of late 1973 and early 1974 ($X = 1$ for 1973 IV and 1974 I, 0 otherwise). We experimented with various declining weight schemes for $X$ in order to measure any effects the embargo might have had on expectations beyond 1974 I, but we were unable to detect such effects empirically. The dummy variable $T$ is included in the weight equation to reflect the shifting of the relationship between weight and quality ($T = 1$ for 1975 model cars, 2 for 1976 models, 0 otherwise). Various vectors of value were considered for $T$, but the results either remained unaffected or deterior-
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ated so that they became meaningless (for example, income elasticity became negative and gasoline price elasticity became positive).

All the current dollar figures have been deflated by the CPI (1967 = 100). The list of variables follows:

\( Y \) = per capita real disposable personal income, in \( 10^{-3} \) dollars
\( r \) = Moody’s Aaa bond yield, on a quarterly basis
\( \delta \) = rate of physical depreciation of cars (\( \delta = 0.0234 \) per quarter)
\( P_G \) = real price of gasoline, 1967 = 100 (the gasoline price component of the CPI, U.S. cities average)
\( P_C \) = real price of new cars, 1967 = 100 (the new cars price component of the CPI)
\( P_K \) = user-cost of new cars, \( P_K = P_C (r + \delta) \)
\( R \) = new car registration per capita, in \( 10^3 \) cars
\( K \) = stock of cars per capita, end of quarter, in \( 10^3 \) cars
\( E^R \) = weighted average efficiency of new cars, miles per gallon
\( E \) = weighted average efficiency of the existing stock of cars, miles per gallon
\( P_{RM} \) = per mile cost of driving new cars, \( P_G/E^R \)
\( P_M \) = per mile cost of driving a car from the existing stock of cars, \( P_G/E \)
\( G \) = quantity of gasoline consumed, in barrels
\( M \) = miles per capita driven
\( L^R \) = weighted average weight of new cars (the number of cars registered in period \( t \) is used to construct \( L \)), in pounds per car.

The various issues of the Survey of Current Business provided the data on \( Y, r, G, P_C \), and the CPI. Data for \( P_G \) (price of gasoline) were obtained from unpublished Bureau of Labor Statistics sources.

Annual figures for the number of cars on the road were obtained from the annual issues of Ward’s Automotive Yearbook; quarterly figures were obtained by interpolating annual figures and by allocating each quarter’s new cars registered to that quarter, on the assumption that depreciation during a given quarter was proportional to registration during that quarter. The various issues of Ward’s and unpublished data supplied us by Ward’s Company, Inc., were used to obtain data for total registration, \( R \). Similar data could have been obtained from the Survey of Current Business; but, since car attributes (such as weight) and stock of cars were available only from Ward’s, for the sake of consistency we chose to use Ward’s registration figures.

Each newly registered car was assigned to one of eight classes of cars (for example, luxury, compact, and so on). For each class a modal car was selected and all cars in that class were assumed to have characteristics—such as weight, gasoline efficiency, etc.—identical to the modal car. Obviously, this procedure was followed so as to render the mass of data less unwieldy. The modal car in each class was that which enjoyed the highest registration figure for the model year; consequently, in some cases the modal car changed from one year to the next because of changes in registration figures (for example, the Chevrolet Nova represented the compact class in 1973, the Plymouth Valiant in 1974).

In constructing figures for overall efficiency of new cars, \( E^R \), a weighted average measure was needed; the problem was what weights to use to come up with overall figures. An obvious possibility was to use registration figures in each quarter as
weights; but this creates problems when, for example, we regress registration on, say, weighted average cost per mile of driving, because we would be regressing registration on some variant of registration. To overcome this problem, one could choose the registration figures for any one quarter and apply those (constant) figures in constructing the weighted average figures; but this approach suffers from the arbitrary selection of the quarter to be used as the benchmark, and the automobile market is too dynamic to justify it. We therefore decided to use the average registration figures of each class during the entire observation period as (constant) weights in our weighted average computations. This approach was used in constructing the overall efficiency of new cars—used in computing the cost per mile of driving new cars, $P^R_M$. (But the average weight of new cars, a proxy for quality $L$, was constructed from the current registration figures.) Accordingly, in equation (13a), the problem of regressing current registration on some variant of current registration is nearly fully overcome; this applies to equation (10a) as well.

Essentially for these same reasons, the rate of depreciation of cars was taken as the average for the entire sample period, with $\delta = 0.0234$ on a quarterly basis.

The collection of data on the gasoline efficiency of the stock of cars raised special problems. The Federal Highway Administration publishes annual data on miles travelled and on the average miles per gallon of passenger vehicles, but these data are of questionable empirical validity. This assessment is based on the fact that the data are derived from estimates of miles travelled supplied by the various states. While we could not undertake an exhaustive study of this estimating procedure, we suspect that the states do not use uniform methods and that some might derive the estimate of miles travelled by multiplying gasoline consumption in the state by the estimate of average miles per gallon. Furthermore, quarterly data are required for this study. Accordingly, we have chosen an alternative route. From various issues of World Cars (Automobile Club of Italy), we obtained estimates of miles per gallon of the various new cars. Following the procedure described above regarding the modal car in each class, we estimated an average efficiency for new cars. We thus obtained a new estimate $E_{t+1}$ for the total stock according to the following formula:

$$E_{t+1} = E_t R_{t+1}(R_{t+1}/K_{t+1}) + E_t (1 - \delta) K_{t+1}/K_{t+1}$$

where $R_{t+1}/K_{t+1}$ represents the proportion of all cars which have the efficiency of the new cars $E_t R_{t+1}$, and $(1 - \delta) K_{t+1}/K_{t+1}$ represents the proportion of all cars, assuming that a fraction of the stock had been scrapped, having the efficiency rating of the stock $E_t$.

As an initial condition, we selected the estimate provided in the Highway Statistics yearbook for the year 1969. However, it became readily apparent that the estimates of efficiency of new cars for the immediately following year were about 20 percent higher. This discrepancy can be accounted for in part by the fact that the new car estimates are based on controlled experiments, while the estimates of the existing stock are supposedly actual car performance. In order to avoid this initial discontinuity in the series, we have elected to deflate all new car efficiency estimates for all succeeding quarters by 20 percent. It should be noted that the empirical results are not sensitive to this assumption.

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11U.S. Department of Transportation (1972), Tables VM-1.
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With the efficiency of the existing stock of cars thus determined, the estimate of the cost per mile of driving the existing stock is then simply \( P_M = P_G / E \). We estimated the figures for number of miles driven from our estimate of overall efficiency of the existing stock of cars as \( M = EG \).

It should be noted that \( P_C \), the real price of new cars as constructed by the Bureau of Labor Statistics, reflects the behaviour of price of standard new cars, that is, their price corrected for changes in quality; thus, variations in quality cannot cause changes in \( P_C \). Detailed descriptions of the manner in which the \( P_C \) index is constructed can be found in the Department of Labor publications.\(^{12}\)

APPENDIX B

The proof of the relationship (6), Section II, is as follows:

\[
\frac{\partial G}{\partial E} = \frac{\partial M}{\partial E} E^{-1} - ME^{-2}\quad \text{from (4)} \tag{B.1}
\]

but

\[
\frac{\partial M}{\partial E} = \frac{\partial M}{\partial P_M} \frac{\partial P_M}{\partial E}\quad \text{from (3)} \tag{B.2}
\]

\[
= - P_G E^{-2} \frac{\partial M}{\partial P_M}
\]

\[
= - E^{-1} P_M \frac{\partial M}{\partial P_M}\quad \text{from (5)}
\]

hence

\[
\frac{\partial G}{\partial E} = E^{-2} \left( - P_M \frac{\partial M}{\partial P_M} - M \right), \tag{B.3}
\]

resulting in

\[
\eta(G, E) = \frac{\partial G}{\partial E} \frac{E}{G}
\]

\[
= - \frac{P_M \frac{\partial M}{\partial P_M}}{M \frac{\partial P_M}{\partial E}} - 1. \tag{B.4}
\]

Similarly,

\[
\frac{\partial G}{\partial P_G} = \frac{\partial M}{\partial P_M} \frac{\partial P_M}{\partial P_G} E^{-1}
\]

\[
= \frac{\partial M}{\partial P_M} E^{-2}\quad \text{from (5)}; \tag{B.5}
\]

\(^{12}\)For example, see Stotz (1966) and Larsgaard and Mack (1961).

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this in turn results in

$$
\eta(G, P_G) = \frac{\partial G}{\partial P_G} \frac{P_G}{G}
$$

$$
= \frac{P_G}{G} \frac{\partial M}{\partial P_M} E^{-2}
$$

from (B.5)

$$
= \frac{P_G}{G} E^{-1} \frac{\partial M}{\partial P_M}
$$

from (4) and (5). \hspace{1cm} (B.6)

Upon summing $\eta(G, P_G)$ and $\eta(G, E)$, the result in (6), Section II, is readily obtained.

REFERENCES


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———: Survey of Current Business, monthly issues.
