GASOLINE USE BY AUTOMOBILES

Robert G. McGillivray, Urban Institute

This paper describes research on the demand for gasoline by automobile drivers. It discusses the relationship between the ownership of and the use and fuel consumption of automobiles. In view of the difficulty in relating behavioral hypotheses about individuals and households to aggregate data, the intricacies of the new- and used-automobile markets are presented. Aggregate gasoline demand models are reviewed and, where available, short-run price elasticities of gasoline are given. Variables, functional forms, and levels of aggregation are indicated. A method of integrating time-series and cross-sectional automobile data and a hypothesis about the prices of services of different sorts of automobiles are discussed. Two other models that simultaneously treat the demand for automobiles and gasoline are reviewed: They are based on (a) the different size classes of new automobiles and aggregate automobile travel as the jointly dependent variables and (b) the new- and used-car markets and aggregate automobile travel as the interrelated entities. These models used only annual data at the national level. Our empirical analysis consists of a single equation model for which the dependent variable is per capita gasoline consumption. The predetermined set includes a lagged dependent variable, demand for new automobiles, deflated gasoline price, and gasoline consumption per automobile at the annual and national levels. Some alternate forms of the hypotheses are given, and the results of estimation are presented and compared. The most reasonable specification produces a short-run gasoline price elasticity estimate of -0.23, a result midway among those of other investigators who have based estimated elasticities on similar data sets.

•ONLY recently has there been interest in modeling gasoline consumption as a consumer product. Most attempts to model gasoline consumption have ignored or have lightly treated possible adjustments in ownership, purchase, and use of automobiles. Similarly, past attempts to model automobile ownership or purchases over time (or over cross sections) have mostly ignored the influence of gasoline price or gasoline consumption as determinants.

This paper surveys some of the recent work on gasoline demand and draws on the literature on automobile demand to suggest the beginning of an integrated theory. Then a gasoline demand equation is formulated and estimated with annual national time-series data for the United States. The results are subjected to formal statistical tests and somewhat more subjective tests of economics and common sense. The preferred specification is used to forecast for 3 years past the estimation period.

Balestra and Nerlove (2) point out the following in their original study of the demand for natural gas:

> While it is true that natural gas is not a durable commodity, i.e., a commodity that is enjoyed repeatedly over a length of time or that may be stored for future use, yet it is also true that the consumption of gas, at least at the household level, is closely related to the stock of gas appliances in existence, and that to a large extent it is governed by such stocks.

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In this sense, gasoline and automobiles are analogous to natural gas and gas appliances. Models that posit that either gasoline consumption or automobile use (similar entities in the aggregate) is determined by gasoline prices or other costs of automobile use are intuitively more palatable than those that ignore the gasoline and other cost of using automobiles.

Having ownership of or access to a gas appliance or an automobile is a necessary prerequisite for its use. The link between fuel consumption (the flow) and the ownership or availability of the durable (the stock) is use. As overall use is changed, fuel consumption changes for a fixed stock of durables. In the shortest time frame for which measurement of fuel consumption is meaningful, little change may be observed in the stock of durables. In such a short term, the effect of a change in the price of fuel is translated primarily into changes in the use of the existing stock of durables. Moreover, since ownership costs are incurred in the purchase of a durable, it is difficult for the consumer to revise choices once the choice is made: Buying, selling, and moving costs, which together make up the transactions or transfer costs of conversion, are too great. Because plans involving the use of durables, such as gas appliances for home heating and automobiles for commuting or business purposes, are relatively inflexible in the short term, a very low short-run price elasticity for these fuels is expected.

But as the time period considered gets longer, the available options expand. Not only can people change their uses of durables, they can exchange the durables for others. In the case of used gas appliances, the market is not interesting. In the case of automobiles there is an active market; it is rather well organized for cars from 1 to about 6 years of age. (The markets for cars less than 1 or more than about 6 years old are small and do not provide much useful information.) The structure of equilibrium prices for used cars provides much data on absolute and relative prices among makes, models, vintages, and among cars with different optional equipment. These data can be supplemented with information on physical attributes and performance characteristics. Such data sets have been used by economists to construct hedonic price indexes from which hypotheses on quality change, on depreciation, and on value differences among cars of different models or vintages can be tested (7, 14).

The decision to purchase a durable differs somewhat from that for the typical nondurable commodity. The usual analysis of a nondurable deals with the purchase and consumption (or the using up) of the commodity in question. But a durable, by definition, lasts for a long period; only its services are consumed during the demand period. The purchase is more of an investment, but investment in a durable, such as a house or a car, is not a business investment, pure and simple. The person may use the durable good for business purposes or for personal satisfaction. For a given level of quality or usefulness, the person may wish to minimize expenditure on such services. In this sense, consumer decisions on durables may be analogous to business investment decisions where the owner of the business chooses to invest capital to maximize profits. Wykoff (19) uses a variant of investment theory in the study of demand for automobiles. A major distinction of Wykoff's analysis is that the relevant price to be considered is the user cost of capital services, which is defined, relative to some time period, as the price of an asset at the end of the year less its price at the beginning plus the opportunity (interest) cost of the value of the capital (money) tied up for a year in the asset. [The recent popularity of this concept in investment theory is due to the work of Jorgenson and others (8, 10, 11, 12).] Wykoff's study goes part way in incorporating the user cost concept into automobile demand analysis. However, his equations include neither the price nor the demand for gasoline, nor do they reflect a personal decision on minimizing or optimizing expenditure for automobile purchase.

Study of cross-section information would be desirable for the formulation of a model based on comprehension of automobile purchase and gasoline consumption behavior. People in different geographic areas and of different physical and socioeconomic levels probably have different needs for automobile services. Farrell (5) has used data on automobile ownership by vintage of car to estimate automobile ownership by household income class. He did not use automobile prices, automobile maintenance costs, or gasoline prices in the cross-section analysis; he used income data to estimate automobile vintage for different income classes of urban families. Then, in a later stage, he inserted his cross-sectional results into a time-series model that estimated a price index for each vintage. Time-series data on income and on prices and numbers of cars owned by vintage were used.

Based on procedures analogous to those used by Farrell (5), it would be possible to explore hypotheses about automobile purchases, ownership, and use for a cross section. However, in the present context, the questions of most interest are those centered on gasoline consumption and automobile size or fuel economy class. No one has addressed these below the state level of aggregation, and cross-sectional or panel data for households are sparse in regard to automobile ownership by make, model, vintage, and in regard to automobile use and gasoline consumption.

Most of the recent studies of gasoline demand use time-series data. A few of these have followed the lead of Balestra and Nerlove (2), who pooled cross-sectional and time-series data at the state level. There have been many more time-series and cross-sectional studies of automobile purchase or ownership. Only two of these have been at all concerned with gasoline price or consumption.

The gasoline consumption models surveyed in the next section and my model suffer from a common flaw: None considers a level of aggregation below the state level. State data do not display much less homogeneous behavior than national data. I have not attempted to extend the work to the quarterly time period or state level because it is not immediately obvious how to disaggregate some of the variables and, more important, because it is also not clear what would be gained from a behavioral standpoint. There would be some statistical gain from an increased sample size, but moving from annual and national to quarterly and state data appears to be going from one crude aggregate model to another crude aggregate model.

GASOLINE DEMAND STUDIES

Recently, because of gasoline shortages, there have been two sorts of studies focusing on gasoline and automobile demand. One is concerned with only the gasoline price elasticity or the forecasting of gasoline consumption; the other centers on the automobile market and concentrates either on vehicle efficiency or on the model mix. (Model has usually referred to five standard market classes based mostly on size and price and a catch-all category, i.e., subcompact, compact, intermediate, standard, luxury, and specialty; however, a new classification is reportedly in the making.)

Gasoline demand has been studied by the Federal Energy Office (16). This model is specified as both monthly and quarterly equations of gasoline demand as a function of gasoline price, personal income, a weather variable (15-year average of national monthly degree days), demand for gasoline in July 1973, and dummy variables for February, March, September, and December. These equations were estimated and used in forecasting. No elasticity analysis is presented in the source report.

Houthakker, Verlager, and Sheehan (9) used a model similar to that of Balestra and Nerlove (2) in the study of natural gas demand. The equation, which was estimated from pooled cross-sectional (state) and time-series (quarterly and annual) data, contains real price, real disposable income per capita, and lagged gasoline consumption. Real, as it applies to real price, means deflated by dividing by the consumer price index (CPI). A slightly more sophisticated way to deflate is to subtract the gasoline component and recalculate an adjusted CPI. For the period examined, the difference between the two was miniscule; therefore, the recalculated CPI was not used. Lagged gasoline consumption is the result of a simple assumption about the relationship between gasoline consumption and automobile ownership, namely that they are proportional and that the constant of proportionality is invariant over time. The short-run price elasticity of demand for gasoline derived from a logarithmic specification of the model is -0.075.

Two models are currently being estimated (18), one of which will be described below. The other, which estimates only a single equation, is for gasoline consumption per capita. Independent variables include real gasoline price, real disposable income per capita, vehicle stock per capita, average vehicle efficiency, and urbanization level.

The observational unit is the state for a given year so that the time-series and cross-sectional data are pooled. Notice that vehicle efficiency and stock are considered exogenous; interestingly, they are treated as endogenous in the other Rand Corporation modeling. The range of short-run price elasticities [annual as opposed to the estimate of Houthakker, Verlager, and Sheehan (9), which was quarterly] for the single equation model was -0.10 to -0.18.

The Federal Highway Administration has estimated a model in which the dependent variable was per capita gasoline consumption (6). The independent variables were real gasoline price and real per capita disposable income. The data were annual time series for several European countries, Canada, and the United States. The price elasticity estimate for the United States equation was 0.364, a counterintuitive sign, but the (null) hypothesis that the coefficient was not significantly different from zero was not rejected. A revised equation using lagged gasoline consumption and a linear specification yielded a short-run price elasticity for the United States of -0.041, which was again not significantly different from zero by the t-test criterion used.

The Transportation Systems Center of the U.S. Department of Transportation has used the FHWA data in estimating some new equations (3). In the first formulation, gasoline consumption was assumed to be a linear function of vehicle efficiency, real income, real gasoline price, lagged gasoline consumption, and the real price of automobiles. Since vehicle efficiency and the price of automobiles enter the equation, it could be considered as a reduced form equation of a more comprehensive structural form involving automobile ownership adjustments; however, the rationale for including them is not made explicit in the paper. The short-run price elasticity was estimated as -0.06, but with a low or marginal t-value. The European data collected by Fields, Nolan, and Miller (6) were also pooled without the American observations, and a linear model of gasoline consumption as a function of price, real income, and lagged consumption was estimated from this data base. The short-run price elasticity was estimated as -0.12 with a marginal t-value.

Two other efforts deserve special mention. Both of these focus on the automobile market rather than directly on the gasoline market. Both use national data to understand the relationships between the demand for new automobiles and gasoline. The first effort considers new and used automobiles; the second looks at the size classes of new automobiles. Both employ an automobile use variable, miles (kilometers) traveled. Gasoline consumption is calculated from information on fuel economy in miles per gallon (kilometers per liter) and automobile miles (kilometers) traveled.

The Rand Corporation developed the single-equation, gasoline consumption model discussed previously and a five-equation (recursive) model. The dependent variables in this recursive model are, in order of introduction, used-car price, new-car demand per household, used-car ownership per household, vehicle efficiency in miles per gallon (kilometers per liter), and vehicle miles (kilometers) traveled per household, which is then translated into gasoline demand per household. The variables used in the five equations are as follows:

1. Real new-car price, real gasoline price, real permanent income, lagged automobile stock per household, and a strike dummy;
2. Real used-car price, real new-car price, income divided by lagged income, and a strike dummy;
3. Real new- and used-car prices, real gasoline price, real income, and a strike dummy;
4. Real gasoline price and a regulatory dummy for whether the year was before 1968 or not; and
5. Real gasoline price, new plus used automobiles, and a regulatory dummy.

The data are annual time series for the nation. The estimate of direct price elasticity for vehicle miles (kilometers) traveled (VMT) was -0.37. The overall gasoline price elasticity was estimated to be -0.83 for the first year and -0.92 for the long run. This elasticity includes effects of price on miles per gallon (kilometers per liter) and automobile ownership as well as automobile miles (kilometers) traveled.

Chase Econometric Associates (4) have also developed a model for gasoline consumption. The model is a seven-equation system designed to forecast new-automobile sales (disaggregated into the six size and price classes previously mentioned) and gasoline consumption. The dependent variables are total new-car registrations, new-car sales in the five separate market classes (excluding the specialty class), and total VMT. Gasoline consumption is then calculated, after some assumptions about sales-weighted fuel economy are made for the classes of automobiles. The variables used in the seven equations are as follows:

1. Real disposable income, unemployment rate, a strike dummy, stock of passenger cars on a new-car equivalent basis, index of credit rationing, gasoline real price index, a dummy for investment tax credit, and a price index for new cars;
2. Unemployment rate and a gasoline price index;
3. Unemployment rate, sales-weighted fuel economy for compact cars relative to all cars, real gasoline price index, and a trend dummy;
4. Sales-weighted fuel economy for intermediate cars relative to that for subcompact cars, a trend dummy, a real gasoline price index, and sales-weighted intermediate car price relative to standard price;
5. Sales-weighted standard car price relative to that for all cars, real gasoline price index, unemployment rate, and a trend dummy;
6. Unemployment rate and sales-weighted luxury car price relative to that for all cars; and
7. Automobile ownership, real gasoline price index, wage and salary component of real personal income, average price of new cars, and change in the consumer price index for all goods and services.

The second through sixth equations represent a system of equations for forecasting market shares of the different size and price classes. The variables used imply that a considerable amount of trial and error led to the final equations. The variable VMT is, therefore, the one through which gasoline price elasticity is felt. The gasoline price elasticity of VMT was calculated to be -0.5, and the gasoline price elasticity of new-car purchases was calculated to be -0.8. There is no obvious way to summarize the effects of gasoline price on market shares or on fuel economy per vehicle, since they are buried in the interrelationships of the model.

DEFINITIONS AND SOURCES

The following definitions and sources are used in this paper:

G_t = passenger-car gasoline consumption, per capita, in gallons (liters), in year t; derived by dividing total passenger-car gasoline consumption by total resident population.
  Gasoline consumption: Federal Highway Administration (17). Includes taxis, motorcycles, and van vehicles (when they are for private use) as passenger cars. Prior to 1960, figures for Alaska and Hawaii were excluded.
  Resident population: U.S. Bureau of the Census (15, Table 2). Excludes U.S. Armed Forces abroad and includes foreign nationals residing in the United States. Figures include Alaska and Hawaii.
G_t^* = new-car gasoline demand, per capita, in gallons (liters) in year t.
A_t = total passenger cars registered, per capita, in automobiles, in year t; derived by dividing total passenger-car registrations by total resident population.
  Passenger-car registrations: U.S. Bureau of the Census (15), Federal Highway Administration (17). Figures include taxis and publicly owned vehicles and are compiled for the calendar year. Prior to 1960, figures for Alaska and Hawaii were excluded.
A_t^* = new-passenger-car registrations, per capita, in automobiles, in year t;

derived by dividing new-car registration by total resident population.
Marketing Services Inc. (13).

λ_t = average gasoline consumption per automobile, in gallons (liters), in year t; derived by dividing total passenger-car gasoline consumption by total passenger cars registered.

P_{gt} = price of gasoline, deflated, in year t; derived by dividing price of gasoline by CPI for all items, in cents.
Price of gasoline: American Petroleum Institute (1). Prices are for regular-grade gasoline per gallon (liter) and include local, state, and federal taxes.
CPI: American Petroleum Institute (1).

r_t = retirement rate of automobiles in year t; derived by dividing the number of automobiles scrapped in year t by cars in use on January 1 of year t.
Marketing Services, Inc. (13). From 1965 on, figures were adjusted by subtracting out those trucks that had been issued passenger-car license plates.

V = automobile miles (kilometers) traveled for the year.

C = gasoline consumption per mile (kilometer) traveled.

a, b = constants.

GASOLINE USE MODEL

In the work discussed, we have used variants of the model specified by Balestra and Nerlove (2) for natural gas. There are differences in our resulting equations since the assumptions about average consumption per automobile and about new-automobile demand have been generalized from their model (2). Our generalizations are partly due to the fact that it is easier to measure automobile purchases and ownership, gasoline use per vehicle, and automobile depreciation than it is to measure the corresponding variables for natural gas appliances.

The most general specification we used indicates new gasoline demand per capita as a function of real gasoline price, new automobile sales per capita, and gasoline consumption per registered automobile. [New gasoline demand is that in addition to gasoline demand carried over from previous periods. In contrast, demand for a new durable can be thought of as new demand and replacement demand for that part of the capital stock that has been retired or otherwise lost through depreciation. Jorgenson and Siebert (11) give a discussion in a capital goods context. Balestra and Nerlove (2) applied this concept to natural gas, reasoning that new demand was a net addition to demand deriving from the existing stock of gas appliances.]

$$G_t^* = f(P_{gt}, A_t^*, \lambda_t) \tag{1}$$

Equation 1 embodies the main behavioral assumptions of the model. It treats new-automobile purchases, use of the automobile stock, and gasoline price as predetermined for the period. Gasoline price is predetermined when there are no supply restrictions; this condition held for the estimation period, but not for the more recent periods of shortages (9). New-automobile demand surely depends on many other variables; as we suggested previously, it is a rather complicated phenomenon in its own right. At the level of aggregation for which the data are available, we decided that, since we could not apply an approach analogous to that of Farrell (5), we could not deal with the interactions between the new- and used-car markets and used cars. [The two general directions in which one could proceed are discussed elsewhere (4, 18). Both these efforts appear to be in the tradition of macroeconomic fishing expeditions where supply and demand factors are considered together to find variable combinations that have good fit. Such procedures have two important defects: (a) Data for the independent variables may be quite difficult to exogenously forecast in their own right, and (b) more reasonable behavioral demand relationships may be obscured by mixing of supply and demand determinants.] The only other such entity that we use in this model is the retirement rate for the entire U.S. automobile fleet, which we introduce later. The gasoline consumption per vehicle embodies two distinct entities. One of these is average gasoline consumption per mile (kilometer), which rests primarily on technological features of automobiles, given a driver's habits and the amount and composition of automobile use. The other is average automobile miles (kilometers) traveled per automobile, which depends primarily on the travel preferences of the automobile users. The first of these entities could be affected by changes in the vehicle or by changes in the way vehicles are driven. The second could be affected by changes in automobile travel demand. These variables were combined into the predetermined variable used because of the aggregate nature of the available data.

Additionally, we specify a pair of identities, one between automobiles and gasoline and the other between automobile ownership and new-automobile purchases:

$$G_t \equiv \lambda_t A_t \tag{2}$$

$$A_t \equiv (1 - r_t)A_{t-1} + A_t^* \tag{3}$$

Without loss of generality we can assume that

$$G_t^* = \lambda_t A_t^* \tag{4}$$

since our subsequent analysis will not depend on what value we use to link G_t^* and A_t^*. If we insert the definition from equation 2 in the definition from equation 3 and use equation 4, we obtain

$$\frac{G_t}{\lambda_t} = (1 - r_t)\frac{G_{t-1}}{\lambda_{t-1}} + \frac{G_t^*}{\lambda_t} \tag{5}$$

$$G_t = (1 - r_t)\frac{\lambda_t}{\lambda_{t-1}} G_{t-1} + G_t^* \tag{6}$$

Under the additional simplifying assumptions, f in equation 1 is linear and

$$a_4 = (1 - r_t)\frac{\lambda_t}{\lambda_{t-1}} \tag{7}$$

We then obtain the equation for estimation (model 1),

$$G_t = a_0 + a_1 P_{gt} + a_2 A_t^* + a_3 \lambda_t + a_4 G_{t-1} \tag{8}$$

The assumption of the linearity of f in equation 1 is simply an assumption of a likely and readily estimable specification. Note that any other assumption on the form of f does not change the relationship between the dependent and lagged dependent variables; it remains linear since a linear relationship follows from the identities in equations 2 and 3. The assumption in equation 7 is more difficult to justify since some data are available on retirement rates and on the ratio of this year's gasoline consumption per automobile to that for last year. One reason for disregarding these assumptions is the quality of the data on retirements; the number of vehicles retired relative to the total is not necessarily a good representation of the depreciation of the stock.

Depreciation is a value rather than a physical concept. As Wykoff (19) has said, counting cars and adding them up are not necessarily the best way to form a capital aggregate for automobiles. His approach would be to normalize on one sort of car such as new Fords in the identity (3). Further, the ratio of gasoline use per automobile this year to that of last is a fuzzy concept at best. λ_t enjoys the role in this model of a scaling factor between gasoline consumption and automobile stock. The meaning of the ratio is unclear for any given year; over the long term it can be thought of as an average annual secular trend in gasoline use per automobile. Finally, the equation to be estimated has five estimable parameters; the parameter a_4 cannot be disentangled to obtain separate estimates of the change in fuel consumption per automobile and the retirement rate. This is consistent with intuition. Suppose fuel economy technology changes radically. λ_t/λ_{t-1} would change during the conversion, but there might be an offsetting change in r_t for the same period.

An alternative way to proceed would be to use the available data on λ_t and r_t directly. The resulting estimating equation has as its dependent variable the calculated value of new gasoline consumption. We attempted this and obtained results that were not easy to interpret. This, at the very least, suggests that the individual annual data on retirements are not an adequate representation of depreciation.

The results of ordinary least squares estimation are given in Table 1. Since the data were annual at the national level for the years 1951-1969, we settled for a single equation and did not attempt to estimate a simultaneous equation model with new-automobile sales or gasoline use per automobile. As mentioned already, an argument could easily be made in favor of a more elaborate model. The insurmountable difficulty is to specify a realistic model of automobile ownership, purchase, retirement, and use with annual national time-series data or with state data.

Table 1 indicates that the fitted equation has signs, t-values, and elasticities that are well within range of both a priori expectations and results of other investigators. The estimate of the elasticity of per capita gasoline demand with respect to its own price, -0.23, which is significantly different from zero at between confidence levels 0.02 and 0.01, based on the two-tailed t-test, lies midway among those of other investigators. The estimate of the coefficient of per capita lagged gasoline consumption, 0.70, is somewhat below expectations, since its calculated value from data on λ and r generally is above 0.9 (Table 2) and indicates that we are not sure of the meaning of a_4. As mentioned, counting automobiles and adding them up may provide an overestimate of the automobile stock. In such a case, retirements understate depreciation.

A variant on the model just presented can be obtained by deleting the variable for gasoline consumption per automobile from equation 1. This gives

$$G_t^* = f(P_{gt}, A_t^*) \qquad (9)$$

If we combine equation 9 with equations 2, 3, 4, 5, 6, and 7 and with the assumption of the linearity of f, we get, instead of equation 8,

$$G_t = b_o + b_1 P_{gt} + b_2 A_t^* + b_3 G_{t-1} \qquad (10)$$

where, in this case (model 2),

Table 1. Per capita gasoline consumption for model 1.

Predetermined Variable	Estimate of Coefficient	Calculated t-Value[a]	Calculated Mean	Estimate of Elasticity	Calculated Standard Error of Elasticity
Constant	-111.68	-2.99	1.000	—	—
P_g	-1.79	-2.99	29.532	-0.225	-0.075
A^*	818.69	7.04	0.038	0.134	0.019
λ	0.32	5.15	664.64	0.894	0.176
G_{-1}	0.70	12.73	226.88	0.674	0.053

Note: R^2 (uncorrected) = 0.998, R^2 (corrected) = 0.998, standard error of regression = 1.838, Durbin-Watson statistic = 1.732, f(4,13) = 1717.212, calculated mean of dependent variable = 234.67, and number of observations = 18. The Durbin-Watson statistic is useless under most formulations containing a lagged dependent variable.

[a] All are significant at the 0.02 confidence level; however those for the constant and P_g are barely significant.

Table 2. Data used in models.

Year	G	A^*	A	P_g	λ	r	$\left(\frac{\lambda}{\lambda_{-1}}\right)(1-r)$
1951	169.864	0.0328636	0.283766	30.0000	598.604	0.0880	—[a]
1952	178.830	0.0265857	0.280051	29.7946	638.562	0.0660	0.996346
1953	186.245	0.0360943	0.291824	30.7833	638.211	0.0890	0.910500
1954	190.951	0.0341878	0.299568	31.0256	637.423	0.0780	0.920861
1955	203.198	0.0434282	0.321623	31.1576	631.789	0.0980	0.894028
1956	210.149	0.0354253	0.322427	31.6051	651.771	0.0920	0.936718
1957	213.773	0.0347791	0.325000	31.5918	657.764	0.0870	0.921394
1958	217.810	0.0266095	0.325329	30.1688	669.508	0.0590	0.957801
1959	225.287	0.0339764	0.334083	30.0394	674.343	0.0840	0.922616
1960	228.717	0.0365389	0.342778	30.1940	667.245	0.0800	0.910315
1961	229.689	0.0319945	0.346448	29.5202	662.981	0.0790	0.915115
1962	235.581	0.0373412	0.355759	29.0702	662.194	0.0810	0.917908
1963	240.037	0.0400902	0.366048	28.5098	655.754	0.0890	0.902140
1964	248.901	0.0422030	0.376243	28.0759	661.544	0.0920	0.916017
1965	259.814	0.0481344	0.389147	28.3439	667.649	0.0960	0.912343
1966	272.551	0.0460532	0.399284	28.3643	682.599	0.1040	0.916063
1967	279.028	0.0423139	0.407089	28.5125	685.423	0.0910	0.912760
1968	293.495	0.0471615	0.419258	27.8135	700.036	0.0980	0.921230
1969	310.079	0.0469067	0.431480	27.0008	718.642	0.0860	0.938293

[a] Not applicable.

Table 3. Per capita gasoline consumption for models 2 and 3.

Independent Variable	Estimate of Coefficient	Calculated t-Value[a]	Calculated Mean	Estimate of Elasticity	Calculated Standard Error of Elasticity
Constant	42.90	1.15	1.000	—	—
P_g	-1.38	-1.38	29.532	-0.173	-0.126
A^*	483.52	2.98	0.038	0.097	0.026
G_{-1}	0.94	21.08	226.88	0.912	0.043

Note: R^2 (uncorrected) = 0.994, R^2 (corrected) = 0.993, standard error of regression = 3.0876, Durbin-Watson statistic = 1.083, f(3,14) = 808.271, calculated mean of dependent variable = 234.67, and number of observations = 18. The Durbin-Watson statistic is useless under most formulations containing a lagged dependent variable.

[a] The t-value is significant at the 0.30 level for the constant, at the 0.20 level for P_g, and at the 0.02 level for A^*. The t-value for G_{-1} is highly significant.

Table 4. Forecast results for model 1.

Year	G_t Actual	G_t Forecast	G_t Forecast/ G_t Actual	P_g	A_t^*	λ_t	G_{t-1}
1970	322.787	327.771	101.54	26.3784	0.041158	737.241	310.079
1971	337.119	346.762	102.86	25.8369	0.047677	749.081	322.787
1972	351.206	363.886	103.61	24.7975	0.05037	758.540	337.119

$$b_3 = (1 - r_t)\frac{\lambda_t}{\lambda_{t-1}} \tag{11}$$

Before empirical results are presented, it is useful to consider another model. Instead of equation 7, suppose that

$$\lambda_t = \lambda \text{ and } r_t = r \text{ (all t)} \tag{12}$$

By combining equation 12 with equations 1, 2, 3, 4, and by assuming the linearity of f, we obtain an equation of the form of equation 9. However, in this case (model 3)

$$b_3 = 1 - r \tag{13}$$

The form but not the interpretation is the same as that in model 2.

The results of estimation for equation 10 are given in Table 3. Again, signs and elasticities are reasonable. In this case, the t-value for real gasoline price is low, significant only at the 0.20 confidence level. The coefficient of lagged gasoline consumption, 0.94, is somewhat higher than one might expect under model 3 and, in fact, is quite consistent with what we would expect from model 2. This can be seen directly by the reader, since the values for (λ/λ_{-1}) $(1 - r)$ are given in Table 2. Recall, however, that they are individually somewhat suspicious and that the r_t and r are not true depreciation rates.

FORECASTING AND POLICY

So that the model may be applied to policy questions, it may be useful to separate gasoline consumption per automobile into its two component parts: gasoline consumption per mile (kilometer) traveled, say C, and automobile miles (kilometers) traveled for the year, say V. These variables are quite dissimilar in terms of the kinds of actions necessary to change them. C is a technological variable; it is the inverse of fuel economy for a given automobile. V is a traveler choice or economic variable. C would be most likely changed by changing the automobile itself, and V would be changed by providing changes in incentives to automobile travelers. As an equation, this is expressed as

$$\lambda_t = V_t C_t \tag{14}$$

A number of policy questions could be addressed by the model. These include the influence of government policy on A^* or on P_g as well as possible actions regarding C or V. In a later paper, some of these will be developed in detail and inserted into model 1. In this paper, remarks are restricted to the estimate of the price elasticity of demand for gasoline.

We tried a logarithmic form for the G^* part of the model. We also reestimated for both forms with 1970, then with 1970 to 1971, and then with 1970 to 1972 data included. Finally, we calculated elasticities for other situations. All these experiments provided results that were consistent with the results for model 1 reported above for the linear formulation based on the estimation period of 1951 to 1969.

A result of particular interest for policy is calculation of elasticities for points other than the point of means. Recall that the linear equation had a gasoline price elasticity of -0.225. The 1972 point elasticity was -0.126 or about 56 percent as great in magnitude. If the 1972 price were doubled, this elasticity would be -0.252. The semilog functional form had an elasticity at the point of means of -0.275, but the 1972 point elasticity was -0.184, or about 67 percent as great in size.

Based on our work and the work of others, we conclude that the short-run price elasticity of demand for gasoline is of the order of magnitude of -0.10 to -0.30 on an annual basis in the sort of market there has been over the past 20 or so years. Note that the extreme shift in the supply of gasoline in late 1973 and early 1974 renders the data on price and quantity for that situation incomparable with earlier and later periods. Most of the change in gasoline consumption for the last quarter of 1973 and the first quarter of 1974 was likely caused by waiting lines at and closing of gasoline stations rather than price increases.

The final quantitative exercise will be to use the model in forecasting the years since 1969 (1970 to 1972) for which data on the variables in question are available. Data are incomplete for 1972.

Table 4 gives the results of using model 1 for forecasting. The forecasts are quite close to and are uniformly larger than the actual results. Furthermore, there is a trend for the forecast error to increase as time goes on. There are two possible explanations for this systematic trend. One is that the specification error of leaving out certain important secular variables causes a misrepresentation of the way in which tastes are changing over time. The other is that the safety and air quality restrictions on the supply side, which began to influence automotive manufacture quite importantly during the forecast period, caused increased automotive costs that in turn had a dampening effect on gasoline demand. These effects were not built into the model except as they might indirectly influence the predetermined variables used.

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