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MODELS FOR PASSENGER CAR
GASOLINE DEMAND IN CANADA

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1. INTRODUCTION

One of the most significant global developments in recent years has been OPEC's dramatic re-valuation of oil prices and the impact of these prices on the world economy. Canada, an importer of crude oil, has become very aware of its dependence upon foreign resources. Since gasoline is the primary petroleum product used in Canada and automobile transportation is the major use of gasoline, an understanding of the automative market for gasoline is crucial to comprehending the degree to which Canada is dependent upon foreign oil.

The concern over dependency on foreign resources for energy has promoted many economists to examine empirically the demand for different types of fuel in Canada. Econometric studies have estimated the demand for fuels for the industrial and residential sector in Canada and the probability of consumer choice of alternative fuel heating systems.

Although the transportation sector's share of oil consumption in Canada is approximately 48 per cent in 1986 compared to the industrial and residential combined shares of about 30 per cent, very few attempts to measure the price responsiveness of gasoline consumption in Canada have been made.

Recently a number of studies of gasoline demand modelling have been published. Section 2 presents a review and full discussion of these studies.

2. RELATED RESEARCH ON GASOLINE DEMAND

Over the past two decades, the number of studies on gasoline demand has grown, and so has the variety and the complexity of the models in their attempt to measure the short-run and long-run response of gasoline consumption to an increase in the price of gasoline. Studies of gasoline demand can be classified into two types, engineering and econometric. Engineering studies usually analyse the physical relationship between fuel economy and vehicle characteristics such as weight, transmission type and accessories and then forecast gasoline consumption on the basis of assumed projections of vehicle characteristics and miles driven by vehicle.

On the other hand, econometric studies focus on prices, incomes and other economic variables which would affect the demand for gasoline. Regardless of their type, the previous studies have used three main approaches: 1- single-equation flow-adjustment models, 2- multi-equation models that explicitly include adjustments in new car sales and total automobile ownership (stock adjustment models), and 3- market models which consider both the demand and the supply side of the market.

Therefore, the following review of previous research is classified into three groups :

1. The flow-adjustment models.
Under this heading there are two closely related types of models, namely, A- Pure or full adjustment model, and B- The partial adjustment model.

2. The investment-utilization models.
Known also as the stock adjustment models.

3. The market models.

1- THE FLOW-ADJUSTMENT MODELS

A. Pure or full flow-adjustment model

This is a single equation model that provides a direct estimate of the price elasticity of demand for gasoline in which full adjustment to changes in the gasoline price is assumed to take one period. Only one study, by Dewees, Hyndman, and Waverman (1975) is presented in this section. Several dynamic specifications were estimated in their paper. However, only the full flow–adjustment model is reviewed here. The single equation model they proposed was estimated using time–series and cross sectional data for the Canadian provinces for the interval 1956–72. The assumption that full adjustment to change in the gasoline prices occurs in one year suggests the following specification :

(1) $\ln G = A + B_1 \ln P + B_2 \ln Y + B_3 \ln URB + B_4 \ln Pc$

Where G = gasoline sales per capita

Pg = price of gasoline deflated by the CPI

Y = per capita personal disposable income deflated by CPI

URB = degree of urbanization, percentage of population living in cities with population at least 10,000.

Pc = price index of automobiles deflated by CPI

The results of the examination are :

(2) $\ln G = \Sigma A_i - .45 \ln P_g + .83 \ln Y - .136 \ln URB - .66 \ln Pc$

(t–statistics) (3.4) (8.0) (1.3) (5.0)

All the coefficient are of the expected sign and all are statistically significant except the urbanization index. The desired signs for P and Y need no comment but comment on the other two variables may be necessary. An increase in the price of new automobiles is expected to result in a decrease in new purchases. A rise in new car prices increases the demand for used cars.

Because the price of used cars is bid upwards, the opportunity cost of scrapping old cars increases in the aggragate there is a decline in new cars but fewer cars scrapped. Since new cars are driven more than old cars the expected net effect of higher new car prices on gasoline consumption is negative.

The authors assumed that, with respect to the urbanization index, the distance travelled in large cities is expected to be lower than in rural areas. Although driving conditions are such that a higher fuel economy might be achieved in the rural areas, overall gasoline consumption is expected to be lower in cities. The availability of mass transit systems in urban centres further supports their hypothesis.

The gasoline price elasticity of demand of − 0.45 and the income elasticity of 0.83 should interpreted as both short and long−run values since no adjustment process is assumed. Clearly, the constraint imposed by the full flow−adjustment model that the entire impact from an increase in the price of gasoline is experienced in the first period is the most unattractive feature of this type of model. In this static framework, the price elasticity is difficult to interpret unless the market is assumed to be in long−run equilibrium at all times.

B. Partial flow−adjustment model

Several recent attempts to estimate a demand function for gasoline have employed models of the following form :

(3) $$Q_t = a + b_1 P_t + b_2 Y_t + b_3 Q_{t-1}$$

Where Q_t = gasoline consumption per capita in period t

P_t = relative price per gallon of gasoline in period t

Y_t = real personal income per capita in period t

Q_{t-1} = gasoline consumption per capita in period t−1

The partial flow−adjustment model, in its simplest form, states that gasoline demand this period is determined by gasoline price, real personal income, and gasoline consumption in the previous period.

The term 'partial flow−adjustment model' has been applied to this type of model because the dynamics of consumption are viewed as an attempt on the part of consumers to bring their actual consumption closer to some desired level. The rationale for this specification is based on the following characterization of the adjustment to change in prices. Immediately following a price increase, consumers can make only small adjustments, such as forming car−pools or foregoing marginal trips. Over longer periods, more adjustments can occur, for example, families can purchase more fuel efficient automobiles and can move closer to their work locations. The most important advantage of the partial flow−adjustment model is that it captures the time − phase nature of the total adjustment to a change. However, the speed of the adjustment is determined by the value of the coefficient of the lagged consumption term; the smaller the estimated coefficient of this variable, the faster is the adjustment to a new equilibrium position. Therefore, when the coefficient of the lagged consumption is equal to zero, the model is called a pure or full flow-adjustment model as it has been discussed above.

The partial flow-adjustment model also provides direct estimates of long-run fuel price elasticity. This is because the coefficient of the lagged consumption term measures the proportion of last period's fuel use, which is carried forward each period following a price change.

The basic partial flow-adjustment model has been estimated using different definitions of gasoline use, data periods, and estimation techniques. Only one study in this catagory is discussed here; the well-known Houthakker, Verleger, and Sheeham study (HVA 1974). In this study, a single equation was estimated using quarterly time-series data from 1963 to 1972 and cross-sectional data from the United States' gasoline and residential electricity markets (the two largest items in the consumer's energy budget).

The authors assume that short-run demand is determined by the stock of automobiles held and economic conditions which influence the level of the utilization of that stock. A desired demand for gasoline is postulated as:

(4) $G^* = A.P_g^{B1}.Y^{B2}$

Where G^* = desired per capita gasoline consumption

P_g = price of gasoline deflated by CPI and Y = real per capita disposable income

The authors suggest the following adjustment process:

(5) $G/G_{t-1} = (G^*/G_{t-1})^{\theta}$ $\quad 0<\theta<1$

which implies a gasoline demand equation.

(6) $\text{In}G_t = \theta \text{In}A + \theta B_1 \text{In}Pg_t + \theta B_2 \text{In}Y_t + (1-\theta) \text{In}G_{t-1}$

The results of the econometric estimation are given below :

(7) $\ln G_t = .593 - .075 \ln P_g + .303 \ln Y_t + .696 G_{t-1}$

(t-statistics)(18.5) (5.8) (17.8) (36.6)

The short-run own price and income elasticity are, respectively, $\in_p = -.075$ and $\in_y = .303$. The long-run price and income elasticities are - .24 and .98 respectively.

Two criticisms of the HVA model have been offered by the authors. The first criticism was that the price elasticities were surprisingly large considering the small proportion fuel costs are of owning and operating automobiles (such criticism was plausible in 1972). The second criticism was that pollution control factors were not accounted for. Thus, for an increase in price of gasoline, consumption of gasoline might be underpredicted, partly due to less fuel efficient automobiles in the fleet.

Critique of the Flow–adjustment Models

The flow–adjustment models avoid a difficult problem in econometric demand analysis namely, separating the stock and flow effects on the demand for gasoline resulting from a price change. However, the approach has two serious limitations. One is that these models can be used to study only one type of policy: that which involves a gasoline price change. They can not adequately analyze other fuel conservation measures designed to increase average fuel efficiency (miles per gallon) of the vehicle stock or to change driving habits (limiting speed). A second and related limitation is that these models say nothing about how adjustments to fuel price changes occur, nor about the relative strength of the adjustment process.

The flow–adjustment models implicitly allow for both discretionary and non–discretionary vehicles uses. In the short–run, only discretionary uses (reducing vehicle miles, e.g, vacation miles) can be altered, whereas non–discretionary miles (miles driven to work) take time to decrease as car–pools are formed or individuals move closer to work.

FIGURE 1

The primary ways in which an individual
can respond to an increase in the gasoline prices :

SHORT–RUN :

(Owns automobile) . driving fewer miles
. scrap their aged automobiles
. drive slower (changing driving habits)

(New car owners) . postpone their vehicle purchase
. choose more fuel efficient cars.

LONG–RUN :

. move closer to work
. use public transportation
. form a car pool
. buy more fuel efficient cars
. purchase fewer automobiles
. manufacturers alter the technology of the newly produced automobiles.
. shift to another type of fuel
(e.g. LPG, LNG or diesel)

While the partial flow–adjustment models are a considerable improvement over the full adjustment model, they do not isolate the effect of a price increase on the activities the individuals can undertake to reduce the cost of a price rise, e.g, drive less miles or more slowly, buy more efficient automobiles, or operate fewer automobiles. These deficiences of the flow–adjustment models are corrected in the next section (see figure 1).

2. THE INVESTMENT-UTILIZATION MODELS

This group of studies includes those which are a variation of the following identity :

(8) $G = \Sigma_i \Sigma_j \; MS_{ij} \; . \; S_{ij} \; . \; 1/E_{ij}$

Where G = aggregate gasoline consumption

MS_{ij} = miles driven per car of type i, age j

S_{ij} = number of cars of type i, age j

$1/E_{ij}$ = gasoline per mile required for car of type i, age j

Most of the recent gasoline demand studies fall under this classification. The models discussed in this section are by :

i. Shalaby & Waghmare (1980)
ii. Pindych-Heide (1979)
iii. Wildhorn (1976)
iv. Burright & Enns (1975)
v. Gallini (1983)

(i) Shalaby and Waghmare (NEB)

This study presents a model for forecasting passenger car gasoline demand in Canada, by region, which was developed in the forecast and market intelligence division of the National Energy Board (NEB). The basic structural indentity for the NEB model is defined by equation (8) above where i= standard and intermediate.

The importance of partitioning the car stock into small and large automobiles is to pick up effects such as the 700 lb. weight decrease in the small cars category btween 1973 and 1977 due to higher gasoline prices. The estimation is based on 1966–1975 time period and Canadian provincial data. The NEB model is discussed in detail below :

(9) New Car Sales per Capita

$NR = \Sigma_k A_k \; - .00413 \; P_c/Y \; - .00938 \; UNR \; - .000422 \; P_g \; - .0799 \; S$

(t-statistics) (1.75) (3.11) (2.1) (5.45)

$$- 275 \times 10^{-9} \times ST - .00609\, DATL(69-70) - .000938\, DSAS(69-71)$$
(5.73) (3.58) (4.3)

Where k = a subscript referring to province k

P_c = real automobile price

Y = regional per capita disposable income

UNR = regional unemployment rate

P_g = real gasoline price in region

S = regional stock of passenger cars at beginning of year divided by driver age population (16 years and older).

ST = man-days lost in strikes in automobile industry

DATL, DSAS = dummy variables for erratic observations for the Atlantic provinces and Saskatchewan for years 1969–1970 and 1969–1971, respectively.

(10) Share of Standard and Intermediate Sales[2]

$$(I + STD)/NR = \Sigma_i B_i - .0163\, UNR - .429\, W/LF + .46\, SP_c/LPc$$
(3.25) (1.0) (3.96)

$$-.000825\ (SE/LE).P_g + .285((I + STD)/NR)_{t-1}$$
(.77) (3.28)

Where SP_c/LP_c = ratio of the sales-weighted average real prices of small cars to the sales- weighted average real prices of large cars.

SE/LE = ratio of the sales-weighted average fuel economy of small cars to the sales-weighted average fuel economy of large cars.

W/LF = proportion of women in the labor force

The short-run elasticity with respect to relative car prices is 0.6; the price elasicity with respect to the gasoline prices is −0.1.

(11) Depreciation Rates[3]

The following equation provides reasonable forecasts for 1972–1975 for the probability of the survival of a car, for each province, given combinations of j, the age of the car and t, the median life of the car.

$$P(j) = (1 + (j/t)^{4.7})^{-1}$$

For example a half life of twelve years implies that 50 percent of the new cars, bought during (t–12), are still on the road at the end of year twelve.

(12) Miles Travelled Per Car

In this model, the forecasts were that, on average, large cars will be travelling 14,000 miles in the first year, whereas small cars will be travelling 13,000 miles in the first year. Data from an Environment Canada survey were used to estimate the following relationships in the model:

(a) small cars: annual mileage per car = 13,000–584j (age of car)
(b) large cars: annual mileage per car = 14,000–547j (age of car)

Moreover, the authors obtained estimates of fuel economies from the Environment Canada survey which analyzed data collected from a survey of 5857 drivers by type of vehicle, age of vehicle, miles travelled per year and fuel economies by province.

The NEB model identifies the price responsiveness of gasoline demand through the type (small or large) as well as the number of car purchases. It measures the price effect only through the size composition of the new car sales.

The major deficiency of the NEB model is that it does not recognise all possible short–run adjustments to the price of gasoline changes. Most importantly, the miles travelled per car is assumed to be independent of the economic environment. Unlike the full flow–adjustment model in which mileage demand responds quickly to a change in the gasoline price with the vehicle stock fixed but the utilization variable, all vehicle miles demand in the NEB model appears to be due to change in vehicle stock (long–run) with utilization fixed. The survival rates of the used cars are also assumed to be exogenous. Thus, the decision to scrap or sell a used car depends only upon the age of the vehicle and no other economic variables are used.

One of the major differences between the NEB model and the other models is the use of the unemployment rate rather than personal disposable income. The authors argue that unemployment rate is a better indicator of economic conditions since it provides more information on expected income[4]. The short-run price elasticities evaluated at the average of the observations, are Ep =-0.163 and Ep = -0.49.

(ii) Pindyck-Heide Model (P-H)

This model of gasoline demand explains the annual consumption of gasoline as the ratio of the total traffic volume, which in turn is the product of average traffic volume per car and the stock of cars, to the average fuel efficiency of the stock of cars. The P-H model consists of six equations estimated with pooled time-series data from 1955 to 1974 and cross-sectional data for eleven industrial countries. The authors tried to answer the question of to what extent and how rapidly the average fuel efficiency and the use of automobiles will change in response to changes in the price of gasoline. The authors argue that because the speeds of the adjustment of the different endogenous variables in the model are an important characteristic of the model, estimation of the model requires variation in all of the variables across time as well as across countries. These variations may then provide accurate estimates of price and income elasticities. However, careful analysis of the inter-country differences in regulations and behaviour which may affect the transportation sector is required. The model for gasoline is given below (countries are subscripted by i).

(13) The basic identity:

$$G = \frac{MS \cdot S}{E}$$

Where G = aggregate gasoline demand
MS = miles driven per car
S = stock of cars per capita at the end of each year
E = miles per gallon

(Note that no age or size distinction is made among cars.)

(14) Stock of cars:

$S = S_{t-1}(1-\delta) + NR$

Where δ = depreciation rate

NR = per capita new car registration

(15) Per capita new registrations:

$$NR = a_i + B^1Pc + B_2Pg + B_3Y + (\theta-\delta).S_{t-1}$$

Where Pc = price index of automobiles[5]

Pg = price of gasoline divided by the GDP deflator

Y = per capita gross domestic product

The above equation is derived under the assumption of a stock adjustment model where S^* is the number of automobiles desired at time t and

(16) $S - S_{t-1} = \theta(S^* - S_{t-1})$

Then, (15) is derived from equations (14) and (16) and is the specification of the desired stock as a function of economic variables[6].

(17) Depreciation Rate:

$$\delta = b_i + b_1Y + b_2Pc$$

(18) Traffic volume per car:

$$\ln MS = c_i + c_1\ln Y + c_2LNPg + c_3\ln MS_{t-1}$$

(19) Fuel efficiency:

$$\ln 1/E = d_i + d_1\ln Pg + d_2\ln 1/E_{t-1}$$

The estimation results for equations (15), (17), (18) and (19) obtained by Heide are given below:

$$(20)\ NR = ai - 79.9\ Pc - .299\ Pg + 1.05\ Y + .589\ NR_{t-1}$$
$$\qquad (-2.39) \quad (-2.85) \quad (1.56) \quad (8.95)$$

$$(21)\ \delta = b_i - 2.93\ .\ 10^{-4}.\ Pc^7$$
$$\qquad (-2.23)$$

$$(22)\ \text{In}\ MS = c_i + .06\ \ln Y + .909\ \ln MS_{t-1}$$
$$\qquad (1.97) \quad (21.4)$$

$$(23)\ \text{In}\ 1/E = d_i - .11\ \ln Pg + .923\ \ln 1/E_{t-}1$$
$$\qquad (-2.3)$$

In order to find the long-run elasticities the model was simulated for a base case for the exogenous variables. Population was assumed to grow at 4% from 1976 levels, Pg was increased at 2% per annum, and Pc was assumed to be constant. The exogenous variables Pg and Y were increased by 10% above the base case to determine the respective elasticities. For the 11-country aggregate, the price elasticity, in absolute terms, is equal to 0.5 after five years, is greater than one after 15 years, and rises to 1.31 after 25 years. The income elasticity is 0.5 after 11 years, implying that short-run fluctuations in income have little effect on consumption of gasoline (the permanent income hypothesis).

There are a few remarks that should be made regarding the above model. The price of gasoline was found to be statistically insignificant and was later removed from the equation (22). As a result, the model fails to capture the individual's primary short-run response to higher gasoline prices - driving less. The price of gasoline might have been insignificant in explaining gasoline consumption per car since fuel economy was omitted from the equation. That is, an increase in the price of gasoline per gallon increases the fuel economy of the fleet (as suggested by equation (23)), thus keeping price of gasoline per mile, the explanatory variable which should have been used to explain miles driven per car, reasonably constant.

While the inclusion of equation (23) represents an improvement, its specification is not quite accurate. For example, a change in the efficiency of automobiles due to an increase in the prices primarily occurs as purchasers of new cars switch to more fuel efficient automobiles. This effect on new car sales may be quite significant and gradually affects the average fuel economy of the fleet. Estimation of the fuel efficiency of the stock of cars rather than the flow of new car sales will tend to bias the impact of the price of gasoline on the fuel economy downward.

Yet another, and final, remark worth mentioning is that the model's estimation of pooling together all eleven countries in one sample is highly controversial.

(iii) Wildhorn, Burright, Enns, Kirkwood (NAV)

This model is known as the New Car Sales/Automobile Ownership/Vehicle Miles (NAV) model. The basic identity of the model is:

(24) $G = M \cdot (1/E)$

Where G = aggregate gasoline consumption
M = total miles driven
$1/E$ = gallons required per mile travelled

The two variables on the right hand side are estimated as functions of economic variables as in the Pindyck–Heide model. Time series data for the U.S.A. from 1954 to 1972 are used.

(25) Used Car Price:

$$P_u = -.896 + 1.7268P_n + .44809Y - 1.4041S_{t-1} - .02959ST$$
$$(-2.052) \quad (5.941) \quad (3.892) \quad (-2.565) \quad (-2.444)$$

Where P_u = price of used cars
P_n = new car price (component of the CPI)
P_g = price of gasoline (component of the CPI)
Y_p = permanent income (weighted average of current and previous disposable income)
S_{t-1} = stock of cars from previous period
ST = strikes in automobile manufacturing; −1 in year of strike, 1 the year after the strikes, 0 elsewhere.

The most significant feature of this model is tha t market conditions in the used car market are modelled separately. the price of new cars is exogenous, as in the other models. That is, the supply of new automobiles is perfectly elastic. However, the stock of used cars is bounded above by the total stock of cars in the previous period. The price of used cars is determined by the demand and supply of used cars in the current period.

(26) New car purchases per Household:

$$NR = -.508 - .20869P_n + .9318P_u + .7305(Y/Y_{t-1}) + .01733ST$$
$$(1.984) \quad (-5.512) \quad (1.632) \quad (2.757) \quad (3.406)$$

(27) Used car ownership per household:

$$UC = -.05894 - .26645P_u + .63665P_n + .22529Y_p - .011865ST$$
$$(-.264) \quad (-2.795) \quad (3.406) \quad (10.669) \quad (-2.068)$$

$$-.59339P_g$$
$$(-4.526)$$

for $UC < S_{t-1}$

$UC = S_{t-1}$ otherwise

(28) Average miles per gallon:

$$\ln E = 2.656 + .17015 \ln P_g - .02228\ D$$
$$(1248.74)(3.673) \quad (-3.296)$$

Where D = dummy for federal regulation and safety and pollution equipment.

(29) Automobile miles driven per household:

$$\ln MH = 9.179 + .86405 \ln S_t - .36853 \ln P_g + .02543\ D$$
$$(752.59)\ (13.36) \quad (3.52) \quad (2.316)$$

the authors assumed that an increase in the price of fuel has the same impact as a decrease in fuel efficiency on total miles driven, given the price per mile is changed by the same amount in both cases. That is:

(30) $\in_{MPg} = -\in_{ME}$

Where $\in_{MPg}$ = the elasticity of miles driven with respect to P_g , the price of gasoline, and $\in_{ME}$ the elasticity of miles driven with respect to fuel efficiency.

The relationship in (30) is used with equations (28) and (29) to get the total miles equation that is used to produce the forecasts.

(31) $\ln MH = 7.996 + .86405 \ln S_t - .44409 \ln P_g - .44409 \ln E$

$+0.03532\ D$

Finally, the gasoline forecast is made from

(32) $\ln G = \ln M - \ln E$

The fuel efficiency equation, equation (28), attempts to measure the rate at which gasoline can be substituted for other inputs (e.g. time, driving slower). The elasticity of sustitution estimated is 0.170. Rather than estimating miles per vehicle as in the Pindyck–Heide study, miles per household is the dependent variable. Since the stock coefficient is less than one, the implication is that the second car is not driven as much as the first car.

The elasticity of miles with respect to the price of gasoline, in equation (29), is smaller than in equation (31). The phenomenon occurs since miles/gallon are controlled for in (31) and not in (29). When the price of gasoline per gallon increase and if miles per gallon also increases (that is fuel efficiency improves), then the number of miles driven will not decrease as much as when fuel efficiency is constant. However, the total short–run gasoline price elasticity can be simply calculated as follows:

(33) $\in_{GPg} = \in_{MPg} - \in_{EPg}$

$= -.44409 + .44409(.17015) - .17015 = -0.539$

There are a few problems which are evident in the NAV model. First, the number of used cars demanded and the supply price of used cars are modelled recursively. Nevertheless, variables left out of equation (31) which explain used car sales in equation (21) are likely to be correlated with the price of used cars in equation (25). The same argument can be made for the endogenous variables of miles driven and stocks of cars. That is, variables not controlled which explain the variation in the number of miles demanded (equation (31)) may also influence the demand for new cars (equation (26)). Second, a dynamic adjustment process is implicitly allowed in the automobiles market. The larger the fleet of cars in the previous period, the lower is the price of used cars and the fewer new cars which are purchased. However, for a given fleet of cars, the demand for vehicle miles is assumed to respond immediately to a change in the price of gasoline. Thus the criticisms of the Flow-Adjustment model are relevent to NAV model too.

(iv) Burright, Enns (Rand Corporation) (RC)

The study is divided into two parts – the first deals with a short run demand for fixed automobiles stock, and the second part models the investment decision in new and used cars. In the short-run the consumer is assumed to have a utility function over two goods, vehicle miles and some other good. The vehicle miles are produced with the inputs of fuel, time, and the fixed automobiles' stock. One result of the utility maximization, constrained by income, is the demand for gasoline

(34) $G = G\{ Pg/P_x, W/P_x, T, Y/P_x, Pc/P_x \}$

Where Pg/Px = relative price of gasonline to price of other goods.
W/Px = relative wage to price of other goods
T = fixed amount of time available.
Y/Px = non-market income relative to price of other goods.
Pc/Px = cost of transportation services deflated by price of other goods.

The authors[8] observe that fuel consumption can be decreased by:

1- driving less, which they call a scale effect, or
2- substituting travel time for fuel by changing driving habits (driving slower), which they call the substitution effect.

The latter implies that miles/gallon will increase, and is described by

(35) $E = E(Pg, W, C_1, \ldots, C_n)$

Where E = miles/gallon

Pg = price of gasoline in real term.

$C_1, \ldots, C_n$ = characteristics of the automobile environment.

Then the relationship in (34), for per capita gasoline demand, can be written as;

(36) $GP = G(Pg, W, E(Pg, W, C_1, \ldots C_n), \ldots)$

The supply of gasoline is assumed to be perfectly elastic as in the other models. Assuming linear functional forms, the supply and the demand equations become

(37) $\ln GP = a + b \ln Pg + c \ln Y + d \ln S + f \ln URB$

(38) $\ln GP = A + B \ln Pg + C \ln Y + D \ln S + F \ln E$

Where URB = percent of population residing in urban areas.

Y = real per capita personal disposable income.

S = automobiles stock per capita.

These two equations were estimated using U.S. data for the 1950–1972 period. When problems of correlation of errors across different states arose they were treated with a generalized least squares procedure. A GLS estimation of equation (37) is

(39) $\underset{(3.5)}{\ln GP = -.66} + \underset{(9.5)}{.19 \ln Y} + \underset{(42.3)}{.93 \ln S} - \underset{(1.8)}{.09 \ln URB} - \underset{(11.5)}{.27 \ln P}$

Which yields a short–run elasticity of – .27 (assuming that S is fixed). The GLS estimation for equation (38) is

(40) $\underset{(6.2)}{\ln GP = .94} + \underset{(10.4)}{.18 \ln Y} + \underset{(41.2)}{.88 \ln S}$

$$+ .29\ PT - .22 \ln P - .78 \ln E$$
$$(3.7) \quad (10.3) \quad (10.3)$$

Where PT = total state vehicles registration as trucks.

From equation (40) the short–run price elasticity of demand is –.22 but this is not the total short–run effect of a change in the price of gasoline. In order to measure the entire effect, an equation for the fuel efficiency was estimated. The results are reported as follows:

$$(41) \quad \ln E = 2.2 + .058 \ln Pg + .001 \ln Y - .06\ PT$$
$$(21.2) \ (11.2) \quad (3.8) \quad (1.9)$$

Thus, the resulting short–run elasticity estimated from equations (40) & (41) is

$$\epsilon_{GPg} = -.22 - (-.78)(.058) = -0.265$$

On the other hand, the long–run model attempts to incorporate changes in scrappage rates in relation to price changes. New and used cars are treated as different goods, but the fuel efficiency is assumed to be the same for all ages of cars. The supply of new cars is perfectly elastic; but the supply of used cars depends on last year's stock.

The model of automobile ownership is :

(42) New Car Sales

$$NR = NR\ (Pn\ ,\ Pu\ ,\ Y,\ Pg\ )$$

(43) Used Cars

$$UC = UC\ (Pn\ ,Pu\ ,\ Pg\ ,\ Y)$$

(44) Used Car Prices

$$Pu = Pu(\ S_{t-1}\ ,\ Pn\ ,\ Pg\ ,\ Y\ )$$

Several specifications and estimation methods were experimented with using national data for 1954–1972 in the U.S.A. For example, normalization of variables by population, households, and driving age population were made and the price of gasoline per mile and per gallon were separately entered into the used cars equation.

The short–run model and the long–run model are combined to determine the long–run elasticities. The authors claim that in the first year 80 percent of the changes in consumption caused by the price of gasoline comes about from driving fewer miles (e.g. vacation miles); the rest is the result of adopting different driving habits (e.g. driving slower). Moreover, the authors state that the third effect (long–run effect) of ownership of more efficient and fewer cars yields a long–run price elasticity between –.64 and –.68 after consumers are fully adjusted to a price change.

The major feature of the RC model is the treatment of time from short–run to long–run. The short–run and the long–run are defined as the time before and after automobile holdings change, respectively. Therefore, the short–run gasoline price elasticity reported in the RC study does not include the changes in automobile purchases in the first year after a price hike. This distinction is important to keep in mind when comparing the "short–run" and "long–run" price elasticities of gasoline consumption estimated by the above model with those found in other models.

(v) Gallini's Model (1983) (GM)

In this study a detailed model of gasoline demand and of technological change in the automobile industry was developed. The GM model indentifies several responses by individuals to an increase in gasoline price. One major feature of the GM model is that it considers the automobile manufacturers' response to a gasoline price increase by altering the technology of the new automobiles produced in the future, given their expectations about changing consumers' demand for more fuel efficient cars.

In the model manufacturers are assumed to choose vehicle designs three years before the commercialization of this vehicle. Given these designs, the price of the automobiles, and the expected mileage costs, individuals decide on the ownership and the characteristics of the vehicle. The utilization of the vehicle is modelled as the outcome of a utility–maximization problem, conditional on vehicle choice. Vehicle holding and used–car scrappage equations and new–car sales ratio equations for three weight–differentiated categories are then examined.

(45) The vehicle utilization decision

The consumer's problem in the GM model is to choose the amount of miles or utilization of vehicle conditional on the automobile holding decision. The consumer wants to maximize his utility function which is defined over vehicle mile and all other commodities subject to nis budget contraint. The results of the maximization is a demand for gasoline per automobile as follows

$$G = g (Pg/e , w , v) / e$$

Where G = the input of gasoline

Pg/e = average gasoline cost per mile

Pc = vehicle cost

w = wage rate which measures both a component of full income (v + wt) and the opportunity cost of time spent in consumption.

v = non-labour income

e = average fuel efficiency or miles per gallon achieved in the vehicle.

(46) The automobile holding decision

The choice among automobiles or some alternative mode of transportation is modelled in this part of the study. Initially, the individual is assumed to decide whether or not to hold a vehicle during the current period. He is assumed to consider the characteristics of the available vehicle, expected gasoline prices in the following period and their car holdings in the previous period.

$$S/D = f(Pc , Pg/e , Y , U , S/D_{t-1} , ST)$$

Where S/D = the proportion of the driving age population that chooses to own an automobile during the current period.

Y = per capita income

U = unemployment rate.

S/D_{t-1} = S/D lagged one time period

ST = men - days lost in the automobile industry due to strikes.

(47) The scrap/sell (or keep) used-car decision

Simultaneous to the decision of whether or not to own a vehicle is the decision of whether or not to scrap a used vehicle by last period's car owner. In addition to economic variables, the age of the vehicle is expected to explain most of the variation in scrappage.

$$U/D = f(\ Pn\ ,\ Ps\ ,\ Pg/e_u\ , Y\ , U\ , S/D_{t-1}$$

Where U/D = the proportion of the driving age population that owns a used car.

Pn = average price of new cars

Ps = scrappage price of a used car

e_u = average fuel economy of used cars

e_n = average fuel economy of new cars

(48) Sales ratio of new automobiles

The author employed a new car choice model using the multinomial logit framework suggested in Cox (1970) for aggregated data. In this model, the probability that a driver with particular characteristics chooses one type of new car over another is estimated as follows :

$$N_k/N_b = f(\ Y\ , U\ , ST\ , (\ P_n^{\ k} - P_n^{\ b}\ )\ , (\ e_n^{\ k} - e_n^{\ b}))$$

Where N_k/N_b = the relative sales of a car of type k to the frequency of car type b purchases for an individual.

$(p_n^{\ k} - p_n^{\ b})$ = difference in price between the two types

$(e_n^{\ k} - e_n^{\ b})$ = difference in fuel economy of the types (reflecting the cost of running the car).

(49) The producer's decision

Automobile manufacturers are assumed to make decisions on the design of ten categories of new automobiles (adopted by the U.S. Environmental Protection Agency) several years prior to marketing them. The fuel economies chosen for the future models are those levels that maximize the present value of the profit stream. The producers' expected revenues are directly related to the expected consumer's demand for fuel economy. To capture the costs of designing a more fuel efficient automobile in a given weight class, dummy variables for the weight classes, DW i=1,...10, are used. Moreover, for the costs of meeting fuel economy standards imposed by the E.P.A. are represented by variables DST.

The manufacturers profit maximization behaviour suggests that the relation for the technical fuel economy of new vehicles in a given class of model year it is given by

$$e_n = f(DST^{75-77} , DST^{78-79} , DW_1 \, . \, . \, DW_{10}, Pg_{t-1} , Pg_{t-2} , Pg_{t-3})$$

where Pg_{t-i} = composite U.S. - Canadian price of gasoline in year t.

(50) The aggregate gasoline demand Indentity

$$AG = G (e) * S$$

Where AG = aggregate gasoline consumption

G (e) = gallon of gasoline per car

s = stock of automobiles.

All the equations in the model are estimated by ordinary least squares using pooled time-series, cross-sectional data. The short-run price elasticity estimated by the model ranges from −0.3 to −0.4 across Canada. The author estimated that 84 percent of this response is due to individuals driving fewer miles, 15 percent due to a change in the size of the fleet and less than 1 per cent to a shift in the composition of the fleet towards more fuel-efficient vehicles. The five-year intermediate run price elasticity ranges from −0.6 to −0.8 and the ten year long term price elasticity ranges from−0.7 to −0.9.

The most important contribution to the above study to the current literature on gasoline demand is the detailed treatment of the fuel economy of passenger cars. In the model, two components of the sales-weighted fuel economy of new cars are estimated separately:

(i). the technical fuel-economy set by the automobile manufacturers

(ii). the sales ratios for three classes of new cars, differentiated according to the natural weight of the vehicles.

As the new car economy gradually changes, this causes the average fuel economy of the fleet to change and hence the gasoline demand per mile to decrease.

The greatest shortcoming of Gallini's work is a lack of data. Because of the data deficiency all used cars are aggregated into one category, which is the main weaknes in the model. Another deficiency in the model is in its analysis of the individual drivers rather than the household's decision. As well the model did not take into consideration other transportation fuels, e.g. diesel fuel, liquified gases (LPG or LNG) nor the different gradings of gasoline e.g. regular, premium or unleaded.

3. MARKET MODELS

This category includes those models in which both the demand and supply sides of the market are considered.

(i) Ramsey, Raasche, Allen (RRA)

This model is presented in a well-known paper (1974). The authors used a sophisticated model in which they introduced gasoline supply and commercial demand as well as household gasoline demand. However, their model is a static one which assumes that market equilibrium is acheived in one year. On the supply side of the market, the share of motor gasoline to total crude supplied is a function of the wholesale price of distillates. Prices of the distillates are assumed to be exogenous to the gasoline market. Letting P_{wg} be the wholesale price of gasoline depleted by a principal components index of distillate prices P_1, P_2 and P_3, G^s be the quantity of motor gasoline supplied, and C be the annual crude oil supply, the supply curve becomes:

(51) $G^s - C_o = f(Pwg_{t-1}, P_1, P_2, P_3)$

The demand side of the market is divided into private and commercial demands. The estimated equations, using time series data from 1947 to 1970 for the U.S. are given below

(52) Private Demand

$$GD_p = f(P_{rg}, P_T, T_p, Y_{t-1})$$

Where GD_p = annual private gasoline demand per household

P_{rg} = retail price of gasoline

P_T = price index of train travel deflated by CPI

T_p = proportion of population in 16 – 26 age groups

Y = real disposable income

(53) Commercial Demand

$$GD_c = f(P_{cg}, P_d, F_c)$$

Where P_{cg} = commercial price of gasoline deflated by the price index of the truck freight rates.

P_d = diesel price divided by the truck freight rate index.

F_c = index of the total ton miles demanded of all freight carriers.

The authors calculate a short run price and income elasticity of demand (private) of –.65 and –1.08, respectively. The above model suggests a reasonable supply side specification and improves the demand side by separating private and commercial demands, public transportation costs and age distribution of the population as explanatory variables of gasoline demand are very interesting additions.

However, the model suffers from its static nature thus, the criticisms of the flow adjustment model are relevent to this study. Moreover, the dynamic process of adjusting to a change in economic parameters is hard to be understood from the model.

<u>(ii) Dahl (1978 DM)</u>

This is another study in which both the consumer's and producer's decision problems are modelled. In this case the purpose of the study was to examine the validity of the charge that the U.S. would consume more energy per capita than other industrial nations when faced with their relative prices. Therefore, the author extended the results by estimating the same model on U.S., Canada, and EEC data to allow a comparison of the robustness of the model and elaticities resluts.

The DM model is a simultaneous system model similar to RRA model. However, the DM model was chosen to avoid simultaneous system bias. The consumer's problem is to choose a quantity of gasoline to maximize utility of vehicle services, which is produced by a combination of gasoline and automobiles, subject to the consumer's income constraint. The result of the maximization is a demand for gasoline, DG, as a function of the price of gasoline, P_g , income, Y, and the price of automobile services. The latter information was not available and thus was proxied by the stock of automobiles, SA. Assuming a log-linear form, the model yields the following demand equation:

(54) $DG = a + b\ Pg + c\ Y + d\ SA$

The next equation is the stock adjustment equation which gives the stock of automobiles as a function of the price of automobiles, PA, the price of gasoline, income , and the lagged stock of automobiles SA_{t-1}. The stock of automobiles was specified as follows:

(55) $SA = e + f\ Pg + h\ PA + i\ Y + j\ SA_{t-1}$

Estimating demand using OLS when the price of gasoline is not exogenous leads to simultaneous system bias. For this reason the author considered the supply side of the market. The producer's problem is to maximize profit by choosing the combination of gasoline and heavy distillates to produce from a barrel of crude oil. On the average, gasoline, residual fuel oil, kerosine, and distillate fuel oil account for nearly 80 percent of a barrel of crude oil. The supply equation was the share of gasoline in a barrel of crude oil as a function of the relative wholesale price of kerosine, PK, distillate fuel oil, PD, and residual fuel oil, PR, and a variable to represent technological improvements over the sample time period, TI. The supply equation is given below :

(56) $GS = k + 1\ PK + m\ PD + n\ PR + w\ TI$

Where PK, PD, PR = the price of kerosine, diesel and residual oil deflated by the wholesale gasoline prices.

The wholesale gasoline price, PW , is used to deflate the distillate prices, but in the demand equation (54) the retail price of gasoline is used. The author introduced equation (57) below to define the retail price of gasoline as the wholesale price of gasoline plus the gasoline tax, TAX.

(57) $Pg = PWg + TAX$

Using U.S time series data for 1953–1972, Canadian data for 1954–1973, and EEC data from 1960–1970 the following results for the elasticities of demand were reported in table 1.

TABLE 1

Long-run elasticities of demand: pooled cross-section time series

Variables	P_g	Y	SA	R^2	DW
U.S.A	-1.048 (7.3)	.322 (6.8)	.545 (7.7)	.88	1.98
Canada	-0.460 (1.4)	.334 (8.1)	.662 (8.4)	.99	1.89
E.E.C	-0.358 (5.4)	.480 (7.4)	.188 (2.6)	.88	1.88

Two comments may be made. First, the DM model may be misspecified since it does not carefully identify exports and imports as well as domestically produced fuels in the supply equation (56). Second, the total gasoline price elasticity of demand for the U.S in the short-run is -0.442, larger than the EEC's long-run price elasticity. the long-run U.S price elasticity of -1.048 is twice as large as Canada's and three times as large as the EEC's.

All the gasoline demand models reviewed in this section are summarized in tables 2 and 3. The data used in the estimation, brief model description and the short & long-run elasticities are included.

(iii) CONCLUDING REMARKS

In recent years, gasoline demand has become the focus of a considerable amount of econometric work. A variety of models, data sets, and time periods have been used to estimate gasoline demand elasticities. The studies show substantial variation between these elasticities. Also, the studies suggest that more of the adjustment to a change in the price of gasoline comes from number of miles driven in the short-run and from miles per gallon in the long-run.

The flow-adjustment models do not seem to pick up long-run price elasticities since these models do not include stock adjustment variables in their specifications. On the other hand, the investment utilization models solve this problem by employing technical variables, such as fuel economy and vehicle characteristics, and economic variables, such as prices, incomes and other related variables. However, each model has its own limitations. Certainly a detailed and careful specification of all the technical features of the stock of automobiles along with the prevailing economic conditions could produce a significant improvement in estimating elasticities for the demand for gasoline in Canada.

NOTES

1- The model did not take account of significant changes designed to reduce air pollution that had been introduced into new cars since 1969 in the U.S. The underprediction of gasoline consumption would be the result of the increased percentage of the new vehicles with their associated air pollution devices and resulting in poor fuel efficiency.

2- The model includes only two classes: small (subcompact) and large (intermediate and standard). The authors estimate equation (10) for the market share of large automobile car models and use it with the new car sales equation (9) to obtain the share of small models residually.

3- The authors were not successful in estimating equations relating to scrappage rates to variables such as income, unemployment, gasoline price and efficiency mainly due to a lack of data on the provincial basis. After surveying work in this field they borrowed from

International Research and Technology Corporation (1976). The equation (11) relates probability of survival of a vehicle to the median life and age of the vehicle.

4- Westin, R, "Empirical implication of infrequent purchase behaviour in a stock adjustment models", American Economic review, June 1975. He suggested that not only the unemployment rate, permanent income and transitory income should be included in new car registrations, but also lagged values for discretionary variables.

5- Price index of automobiles is defined as the ratio of expenditures of personal transportation equipment in current purchaser value to the expenditures of a base year, divided by the GDP deflator.

6- If equation (15) were derived from a stock adjustment model, it should not contain the lagged new registrations term. The model and the results are reported directly from the referenced study.

7- Y variable found to be statistically insignificant.

8- In equation (34) the demand for gasoline is normalized, implying homogeneity of demand, a classical assumption of the consumer theory. The homogeneity of degree zero in the demand function suggests that if price and income increase by the same properties, there is no change in the quantity demanded.

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