THE DEMAND FOR PETROL IN THE UNITED KINGDOM,
1955-1973: AN EMPIRICAL INVESTIGATION

by

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ABSTRACT

This study attempts to analyse the factors that are likely to influence demand for petrol in the United Kingdom, through a model building approach based on pragmatic considerations.

Petrol demand is considered as arising mainly from variations in desired car ownership, car consumption characteristics and car utilisation rates which are the outcomes of decisions taken with respect to changes in the economic environment. This assumption leads to the construction of a four-equation econometric model which is estimated on the basis of data covering the period 1955 - 1973. The model's validity is tested for the years 1974 - 1976.

The estimates derived suggest that petrol price increases are unlikely to affect short-run petrol demand, which appears as both price and income inelastic. In the long-run however significant petrol price increases may result in people looking for more economical (from the point of view of petrol consumption) cars.
ACKNOWLEDGMENTS

I would like to express my gratitude to my supervisor Professor C. Robinson for his continuous advice and encouragement throughout all phases of this dissertation.

Thanks are due to my colleagues and friends Drs P. Arestis, E. Karakitsos, C. Timms and R. Ireson for their help at various stages of this study.

The members of the Energy Group of the Department of Economics at the University of Surrey to whom an earlier version of this work was presented made many constructive criticisms and suggestions.

Last but not least I wish to express my utmost appreciation to my wife Elli both for her comments and patience during the period of this study, and to my parents Triphon and Eleftheria for their wholehearted moral support.
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INTRODUCTION

The purpose of this study is to examine the factors that are likely to influence consumer demand for motor spirit in the United Kingdom, and to evaluate the response of economic units — in the form of estimated elasticities — to changes in the economic variables considered to determine demand, directly or indirectly, during the period 1955-1973.

The study is part of a more general attempt by the Department of Economics at the University of Surrey to analyse markets for energy products and derive useful quantitative knowledge relating to the demand for these products.

Until a few years ago little useful work had been done on the demand for motor spirit either in the United Kingdom or in other countries. However, the events of 1973, the so-called 'energy crisis', apart from leading to reconsideration on the consumer's part regarding his consumption patterns, also brought about some new interest on the subject. The number of research papers that have appeared since then verifies the view that crisis is the mother of analysis.

For most of the 1950s and 1960s the price of motor spirit, as indeed of most energy products, appears to have fallen in real terms. The concentration of sellers on marketing actions aiming at sales promotion — such as gifts offered — indicates that the product was in a buyers' market. Excess capacity in refining strengthened the influence of independent marketers, whose emergence often resulted in price wars. In selecting new cars most consumers paid little attention to miles given by a specific car per gallon.
of motor spirit.

However, after 1973, the position was reversed. Actions such as conservation campaigns or imposition of speed limits were directed towards decreasing the demand for motor spirit. Policy measures such as these require some quantitative knowledge as to how consumers are likely to react to changes in their economic environment. Hence it appears that 'what is needed is some econometric evidence on the likely response of aggregate demand to higher prices, but unfortunately there is nothing available; even for individual fuels there is little evidence on price elasticities'**.

The decision to respond to the above call by providing econometric evidence of price (and income) elasticities of the demand for motor spirit was based on some important considerations. First, almost without exception there is a strong technological complementarity between the demand for energy products and the corresponding consuming units (energy consuming appliances) which to a great extent govern that demand. A realistic investigation thus, would call for a consideration of some sort of stock of appliances effect.

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Unfortunately, information relating to stocks of most energy consuming appliances is rather rare and this has led investigators either to base their analysis on stock data of questionable quality* or to resort to mathematical manipulations. The latter are used in order to eliminate the influence of the (unknown) stock variable from the relevant demand equations and thus to isolate short-run variations in the quantity demanded due to variations in the rate of utilisation of the appliances**. Without such transformations, an analysis of the demand for energy products would be of very limited use. Moreover it would create the difficulty of conceptually distinguishing between products that like, say, oranges or apples give satisfaction directly,


and products whose demand is derived from the demand for services of the underlying consuming equipment. Mathematical transformations of this type, though, impose the restrictive assumption that stocks increase at a certain constant rate over time. Hence, the estimates obtained as well as the conclusions based upon them are unavoidably influenced by an assumption that may not be realistic. If one wishes to produce some useful work in the field of energy demand one should resort to this sort of assumption only as the last solution. However, sufficient information relating to the U.K. stock of petrol consuming motor vehicles has been found to make this type of assumption unnecessary in an empirical investigation of motor spirit demand.

Second, the development of applied energy demand analysis is probably better served by the careful study of elementary phenomena than by the pursuit of complex theoretical structures. Throughout the study an attempt was made to keep a balance between the requirements of academic research and the practical questions which an empirical investigation is aimed at answering. Nevertheless, whenever a crucial decision had to be made common sense rather than academic elegance was given priority. Implicit in this decision there was a remark that followed the presentation of a paper by M.J. Farrel on the demand for motor cars in the United States. A. Webster, one of the participants, said that he was concerned to some extent with the determination of demand and he was glad to see academic research, always hoping that it could be turned to practical use. But,
'frankly so far he added 'I do not see what has been presented to us this evening could be so turned'*. 

The contents of this study may be summarised as follows:

In chapter 1 the interrelationship of the motor spirit and car markets is stressed and an outline of the developments that took place in them before and during the period under investigation is given.

In chapter 2 the extent to which classical theory may be of help to an investigator of the demand for motor spirit is evaluated and a simple price-income model, representing an approximation of the postulates of demand theory, is tested. This leads to a questioning of whether such a model may provide a realistic explanation of the observed facts. It also calls for an examination of how others have treated the problem of the demand for motor spirit.

The review of the relevant literature in chapter 3 suggests that the problem has been tackled in two different ways: through the use of data relating to technological characteristics of cars (engineering approach) and through the use of information concentrating on socio-economic variables (econometric approach).

Nobody, so far, has tried to reconcile the two different lines of thought by combining engineering type data into an econometric model or vice versa. This is attempted in chapter 4 where the naïve price-income model is modified

and strengthened so as to be able to describe the processes at work as realistically as possible. The stock of equipment effect, which is so important in energy demand studies, is incorporated in the model along with a variable (average engine capacity of private cars in use) standing as a proxy for the consumption characteristics of the average car.

Nevertheless, to conclude that apart from the price of motor spirit and consumers' income, the number of cars in use and their consumption characteristics are the most important factors in a demand function for motor spirit would be equivalent to going only half way towards the requirements of an economic investigation. Variations in the last two variables are the outcome of economic decisions as well, that have to be described in terms of behavioural equations within a multi-equation model. Chapter 5 deals with the construction of such a model and its statistical estimation. This may be taken as an additional contribution of this study towards the problem of establishing a demand function for motor spirit not only in the U.K. but, data permitting, in other countries as well.

Chapter 6 is devoted to a non-technical summary along with some conclusions and recommendations for further research.
Chapter 1

Historical Background

1.1 Interdependence of the car and petrol markets

An investigation of the demand for any product should be preceded by an examination of the existence of commodities which are close substitutes for or complements to the commodity under consideration. Failure to recognise the importance of related goods and the likely influence of their prices or quantities sold or possessed on the quantities demanded of the product under study may give rise to misleading conclusions. G.J. Stigler, ordering the determinants of the demand for a product, stresses that the prices of related goods are the second major factor. The purchases of automobiles, he argues, will depend upon the price of gasoline.*

The complementarity of goods stems from the nature of consumer tastes, which result in some products being habitually consumed together, for example, bread and butter, or from some technical relationship which makes one necessary if the other is to be enjoyed. It follows that complementarity need not exist for all times - tastes may change or technology may alter (for example, electric power-driven motor vehicles may replace petrol-driven cars).

In the post-war period petrol and motor cars have been closely complementary in the technological sense. Such a relationship dictates that a successful study of petrol

* G.J. Stigler: 'Theory of Price', 3rd edition,
demand should not only concentrate on developments in the petrol market alone but in the car market as well, given that changes in one will inevitably affect the other. Since the decision of an individual to consume petrol follows the decision to buy a car, a brief look at the car market is taken first.

1.2 An overview of the car market*

For an idea of the growth in car ownership over the past decades the language of figures seems to be more appropriate than a verbal description. In 1904 the total number of private motor vehicles in use in the United Kingdom was 8465; by 1973 the level of car ownership was 13805 thousand (figure 1, for 1955-73). Taking into account changes in population this implies that the ratios of cars/persons were 1:3890 and 1:4 respectively. This pattern of growth by and large, seems to justify the view that "when the product is first introduced there is likely to be a certain amount of suspicion among consumers for a time - partly an emotional reaction to something new which might appear likely to render obsolete one's well tried possessions, and partly a knowledge, well founded in experience, that those

Growth in private car ownership in the United Kingdom:

1955-1973

Number of cars in use (million)
"who buy new durables in their early stages are likely to suffer from teething troubles which later purchases will avoid".*

Particularly in the very early stages the number of people who wanted a car was small even if their income did not impose serious constraints. The attitude towards cars may best be given by the following quotation from Birmingham Post (20 April 1907):

"This year will see a colossal weekly output of motor cars ... the total ... per week is not far short of ... 250 ... To the casual observer it doubtless appears that soon this rate of supply must diminish, since all those who require motor cars will have been supplied".

The first expansion of the car market was significantly helped by drivers' training during the World War I, gratuities given at the end of it and relatively low prices charged by Morris. After the Second World War, other factors such as rising consumers' income,** credit facilities and changes in consumer taste induced by advertising campaigns became more significant; furthermore the pattern of development

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** Its average rate of growth over the period 1955-1973 was approximately 2.5% per annum.
of passenger transport services was an area where price movements probably exerted at least a reinforcing effect. Especially during the period 1950-1969 rail and bus fares rose very much faster than private motoring costs, with the main increases in both cases taking place when traffic declines were at their peak. *

On the supply side the main contributing factor was technical progress, that is new techniques of production which have become more predominant as a result of continuously growing demand. The post war period has seen the second stage in mechanisation with the introduction of automation, the first stage being a gradual introduction of mechanised production techniques during the inter-war period. The introduction of automation brought, as expected, a considerable increase in the output of standardised items and this in turn a reduction of unit costs. An idea of the transformation of the industry due to automation may be given by the fact that in 1939 the amount of labour required for the production of 1700 vehicles by Austin was 997500 man-hours. In 1960, four years before the period of slow growth in output (see

page 14) with approximately the same amount of labour (977,500 man-hours) production was almost four times higher than the 1939 level (67,500 vehicles).

The main developments in the private car market between 1955-1973 were as follows*:

Production in 1955 reached a peak as a result of a recovery which started in 1953 following a budget designed to stimulate home demand. Measures such as the reduction in the standard income tax rate by 6d (2.5 new pence), were thought necessary in order to counterbalance the effects of deflationary measures introduced after the Korean crisis in 1950-51. To the latter one should add the unfavourable influence of steel shortages which became acute in 1951 and 1952, and the results of a transition period during which factories were being transformed from war-work to car production, which considerably affected the industry. The stimulating measures of 1953 contributed towards 1955 emerging as a boom year, characterised by rising incomes, low unemployment and a stretch of the economy's producing capacity to its upper limit. However, in 1956 the first setback appeared as a result of credit squeeze, import restrictions abroad (especially in Australia and New Zealand, the industry's most important markets) and the Suez crisis. Oil supplies were affected and the introduction of petrol

* A statistical summary of these developments is provided in table 1.
rationing and a significant petrol tax increase of 5 pence a gallon hit the car industry seriously. As table 1 shows the registrations of new cars fell by almost 20% (from 513 thousands in 1955 to 409 thousands in 1956) while exports fell by 14% (from 391 thousands in 1955 to 336 thousands in 1956). In 1957 production started recovering and the government's expansionary measures that followed led to a new peak in 1960 (table 1). The most stimulating factors were the initial relaxation and later removal of hire purchase restrictions in 1958* and the reduction of the standard income tax rate by 9d in 1959. The first signs of over-heating of the economy soon appeared and a special Budget was introduced in 1961 intended to counterbalance the inflationary pressures by decreasing home demand and encouraging exports. Towards this purpose the maximum permissible surcharge (10%) on customs, excise and purchase tax was imposed, and the government launched a campaign aiming at low export prices through wages restraint. The consequences of such a policy constitute a good example of the long-standing problem of conflicting points of view between the government and the motor industry. The government want higher exports, but at the same time they cannot refrain from trying to regulate the economy by manipulating home demand for cars through various restrictions or tax increases; manufacturers take the view that 'only high and guaranteed home sales can keep costs low enough

* See table 28, in chapter 5, where the influence of hire purchase restrictions is discussed in some more detail.
to allow them to export and still make profits'.* Car production was 1004 thousand cars in 1961, a decrease of 25.8% compared to the previous year's production, while exports fell by almost 200 thousand cars (from 570 thousand in 1960 to 371 thousand cars in 1961; table 1). In 1962 there was an upturn and a strong boom emerged in the following two years as a result of relaxation of controls and an upsurge in real per capita income. Overall, the period 1955-1964 may be characterised as a period of rapid average production growth with its rate being 8.5% per annum.

From 1964 to 1973 there was little net change in output; the average growth was only about 0.2% per annum. A possible explanation is the reinforcement of restrictions particularly after the devaluation of sterling in November 1967. The fall in production growth between 1965-1968 was the longest and most severe since the war. Exports rose after the 1967 devaluation for two years, new registrations remained unchanged in 1968 (compared to 1967) but fell in 1969. An increase in home demand in the years that followed (after 1969) coincided with a boom in imports and an almost continuous fall in exports** (table 1).


** The situation is more disappointing if one considers the world export market in terms of shares. Here the UK's share gradually declined from around 55% in 1950 to approximately 13% in the early 1970's. See: D.G. Rhys op.cit. p.384.
The "export at all costs" policy adopted in the first half of the period under consideration seems to have had undesirable hang-over effects later. Production rush for world markets during 1955-64, was given priority at the expense of quality considerations, establishment of better service network overseas and labour relations. The first two factors harmed for some time the reputation of British vehicles while the latter resulted in production shortages caused by strikes, which in turn affected home and foreign sales.

The periods of stagnation in domestic demand on the other hand, reduced total output to levels where total unit costs increased and return on capital before tax for seven British firms decreased to 1.8%, compared to a 10% return of the main rivals, that is German and Italian manufacturers.* The higher rate of return on capital of European car firms strengthened their competitiveness and helped their establishment in new overseas markets through aggressive pricing policies. In the U.K. market, intensity of sale-efforts on the part of foreign firms often took the form of selling at prices lower than variable costs. This in conjunction with reductions in tariff barriers resulted in a higher volume of imports.

The general conclusion that may be drawn from the developments outlined above is that prices of cars reflecting changes in the input markets, growth in disposable income

* D.G. Rhys, op cit. p.399.
and some index of government intervention* should be a satisfactory set of economic variables for the explanation of variations in the demand for car ownership. However, long waiting lists were often a common phenomenon in the U.K.**, and this is an indication that car demand has not always been satisfied, at least on time. This implies that one should take into account the possibility of a gap between the desired and actual levels of car ownership. This consideration is taken up when the model of the demand for petrol takes its final form (see chapter 5).

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* The degree to which the car industry may be affected by specific government measures, such as hire purchase regulations has been pointed out by students of the industry. It has been suggested that a reduction in the minimum hire purchase deposit from 33 to 20 per cent would affect net additions to car stock by as much as a 2% real GNP growth. See: A.G. Armstrong: 'The Motor Industry and the British Economy', University of Cambridge, Department of Applied Economics, 1967, Reprint Series No. 275, p.22.

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1.3 The Petrol Market in the United Kingdom

1.3.1 General Background

The United Kingdom provides one of the largest single national markets for petrol in the world*. The term 'petrol' or 'motor spirit'** is applied to refined petroleum as used in normal spark ignition engines, mostly motor car engines. Motor spirit is one of a number of products, including kerosene, fuel for diesel-powered engines, fuel oils, lubricants and naphtha, manufactured from crude oil. The type of the latter constitutes, in principle, the main factor determining the refined products' proportions that may be obtained out of a barrel of crude oil (table 2). Nevertheless, subsequent processing permits both an increase in quality and/or the share of a specific product***. This process of distillation and "cracking" allows substitutability of the various products for each other, at a cost which depends on the existing distillation technology.


** The terms 'motor spirit' and 'petrol' are interchangeably used in this study. In a strict sense, 'petrol' should refer to other engine spirits as well (for example, aviation spirit).

*** The share of motor spirit in total output is given in table 3.
### Typical United Kingdom Refinery Production

<table>
<thead>
<tr>
<th>Product</th>
<th>% of total throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gases (Butane and Propane)</td>
<td>1.6</td>
</tr>
<tr>
<td>Naphtha</td>
<td>5.8</td>
</tr>
<tr>
<td>Gasolenes (petrol)</td>
<td>13.5</td>
</tr>
<tr>
<td>Kerosene (paraffin)</td>
<td>6.3</td>
</tr>
<tr>
<td>Derv and Gas Oil</td>
<td>24.9</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>36.0</td>
</tr>
<tr>
<td>Other Products</td>
<td>4.6</td>
</tr>
<tr>
<td>Refinery fuel and losses</td>
<td>7.3</td>
</tr>
</tbody>
</table>

Before and during the Second World War most of the petrol consumed in the United Kingdom was refined abroad but a number of new refineries have been set up in this country since the war, with the result that the bulk of imports of petroleum products now consists of crude oil*.

At the end of 1973 refinery capacity in the United Kingdom totalled almost 140 million tons a year, compared to 31 million tons in 1955 (table 3).

Several factors contributed to such a spectacular increase over the period 1955-1973. A desire to save foreign currency and the high costs of imported finished products relative to crude oil costs constitute the main economic reason. Technical developments such as the introduction of super-tankers brought about considerable economies of scale in transportation and permitted the economic exploitation of a larger range of by-products. To these reasons one should add a desire of self-sufficiency on the part of the industry since the risk of depending upon foreign refinery capacity appeared greater than the risk of depending upon foreign crude oil.

The quantitative growth of new refineries was accompanied by considerable qualitative developments. In the early days of the oil industry the simple product fractions were directly used as saleable products. Nowadays, however, products have to be specially tailored in order to satisfy demand requirements. Hence, a high degree of flexibility is a necessary feature of a modern refinery, since it permits

* Monopolies Commission, op. cit.
### U.K. Refinery capacity and activity, 1955 - 1973

<table>
<thead>
<tr>
<th>Year</th>
<th>Refinery capacity installed (thousand tons) (1)</th>
<th>Total output of Petroleum products (thousand tons) (2)</th>
<th>Motor spirit produced (thousand tons) (3)</th>
<th>Motor spirit as % of total output (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1955</td>
<td>31,135</td>
<td>25,011</td>
<td>5,793</td>
<td>23.16</td>
</tr>
<tr>
<td>1956</td>
<td>30,438</td>
<td>25,976</td>
<td>5,625</td>
<td>21.65</td>
</tr>
<tr>
<td>1957</td>
<td>34,018</td>
<td>29,171</td>
<td>4,963</td>
<td>19.72</td>
</tr>
<tr>
<td>1958</td>
<td>42,300</td>
<td>29,771</td>
<td>5,429</td>
<td>18.24</td>
</tr>
<tr>
<td>1959</td>
<td>43,351</td>
<td>35,321</td>
<td>6,155</td>
<td>17.43</td>
</tr>
<tr>
<td>1960</td>
<td>49,220</td>
<td>40,266</td>
<td>6,632</td>
<td>16.46</td>
</tr>
<tr>
<td>1961</td>
<td>50,655</td>
<td>44,900</td>
<td>7,040</td>
<td>15.68</td>
</tr>
<tr>
<td>1962</td>
<td>51,776</td>
<td>48,131</td>
<td>7,024</td>
<td>14.59</td>
</tr>
<tr>
<td>1963</td>
<td>57,166</td>
<td>48,810</td>
<td>6,803</td>
<td>13.94</td>
</tr>
<tr>
<td>1964</td>
<td>65,826</td>
<td>53,714</td>
<td>7,659</td>
<td>14.26</td>
</tr>
<tr>
<td>1965</td>
<td>72,233</td>
<td>59,946</td>
<td>8,605</td>
<td>14.49</td>
</tr>
<tr>
<td>1966</td>
<td>82,493</td>
<td>65,263</td>
<td>8,677</td>
<td>13.30</td>
</tr>
<tr>
<td>1967</td>
<td>84,878</td>
<td>66,893</td>
<td>8,823</td>
<td>13.19</td>
</tr>
<tr>
<td>1968</td>
<td>96,013</td>
<td>75,532</td>
<td>9,379</td>
<td>12.37</td>
</tr>
<tr>
<td>1969</td>
<td>107,691</td>
<td>83,743</td>
<td>10,065</td>
<td>12.02</td>
</tr>
<tr>
<td>1970</td>
<td>112,581</td>
<td>93,200</td>
<td>11,167</td>
<td>11.98</td>
</tr>
<tr>
<td>1971</td>
<td>119,523</td>
<td>96,693</td>
<td>12,324</td>
<td>12.75</td>
</tr>
<tr>
<td>1972</td>
<td>121,880</td>
<td>97,797</td>
<td>13,417</td>
<td>13.72</td>
</tr>
<tr>
<td>1973</td>
<td>139,800</td>
<td>104,280</td>
<td>14,608</td>
<td>14.01</td>
</tr>
</tbody>
</table>

**Sources:** Columns 1-3: Digest of U.K. Energy Statistics 1967 and 1974, tables 135, 136 and 29, 32 respectively.

**Column 4:** Calculated.

*Maximum obtainable capacity in normal operating conditions, allowing for scheduled periods off-stream for technical reasons.*
transformation of heavier fractions into lighter and more valuable ones.*

The U.K. petrol market may be divided into two categories. The retailers, who buy for subsequent resale to the general public, and commercial consumers, who buy for their own use. Ideally, an empirical analysis should distinguish between the above two categories. However, the quantities recorded in the official statistics as demanded by commercial consumers tend to be underestimates of "business" use. This is because some commercial consumers satisfy part or all of their requirements through retail petrol stations. Thus a distinction between commercial and non-commercial demand on the basis of those figures would be misleading. Instead, one can rely on information relating to total annual quantities of motor spirit demanded, and gradually modify the analysis of petrol demand on the basis of estimates published and referring to demand by end-use.**

1.3.2 Product characteristics

One of the most important characteristics of petrol as a motor fuel is its uniqueness. Other products such as kerosene, alcohol, diesel oil and liquefied petroleum gas have been mentioned as possible substitutes for internal


** That is demand attributed to different categories of motor vehicles, such as private cars, commercial vehicles and so on.
combustion engines, but for technical as well as economic reasons the use of the first two has been totally insignificant.

In contrast, the greater heat value of a gallon of diesel oil relative to that of a gallon of petrol and the greater thermal efficiency of a diesel engine compared to a petrol engine probably constitute the main reason for the establishment of diesel oil as a satisfactory substitute fuel in some cases*. A combination of these two advantages means that even if the per gallon price of diesel oil were equal to that of petrol, the cost of fuel per mile travelled would be lower in the case of diesel-powered engines. Nevertheless, the relatively high initial cost and weight of a diesel engine have limited the use of diesel-powered engines to some categories of motor vehicles, mainly buses and heavy commercial vehicles.

The above implies that for the most predominant category of motor vehicles, that is private cars, there are no good substitutes for petrol. This has led some economists**

* According to some figures given by C. Broome, the heat value of a gallon of diesel oil is 4.5% greater than that of a gallon of petrol. The efficiency of a diesel engine is 40% greater than the efficiency of a petrol engine. See: C. Broome: 'An Analysis of the Elasticities of Demand for Gasoline in Alabama', unpublished Ph.D Thesis, University of Alabama, 1964, p.33.

to conclude that the price elasticity of the demand for petrol is likely to be very low. Such a possibility is strengthened by the fact that petrol is jointly demanded with other products necessary for the satisfaction of the demand for private transportation (see section 1.3.4).

1.3.3 Quality

In the U.K., petrol is sold branded, in three main qualities described by different superlatives by different companies, and according to a British standards classification which allows petros with different performance characteristics to be sold as falling within the same class.

There are some real and fancied differences between brands and it could be argued that the very complex chemical structure of petrol would be a barrier for the average consumer towards judging between alternative brands. Nevertheless, competition in quality ensures that petros in each class will be close substitutes for one another. This conclusion was reached by the Consumers' Association who "found little difference between different brands of petrol, all brands performed their function well".*

Qualitative competition has led to a continuous improvement of the product, without a corresponding increase in price. Between 1953 and 1969, for instance, standard petrol was raised in octane number from 75 to 91, while the net price received by oil companies for this grade fell by 10%**.

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* Consumers' Association: "Which?", January 1964, p.11.

But due, mainly, to tax increases as well as to retail margins, consumers did not benefit from such reductions as shown in table 4.

1.3.4 Petrol costs relative to other motoring costs

In general, jointly demanded products whose share in total costs is relatively small are considered as price inelastic. Hence the proportion of petrol costs in other outlays on motoring is, obviously, of some interest.

In "Motor Business"* a study was published in which motoring costs in the U.K. are divided into two categories: running costs, that is costs arising when a car is in use, and standing costs which are independent of use**. This classification is analogous to the distinction between fixed costs and variable costs of economic theory. This analogy permits the conclusion that as in the case of a producing firm it is variable costs that, in the short run, determine the amount of output to be produced, similarly variable (running) costs are the costs that may influence consumers' short run behaviour (rate of car utilisation).


** Standing costs = Licences, insurance, garaging, HP interest and generally costs that are independent of use. According to 'Motor Business' these costs amounted to £465 million in 1962 bringing the total expenditure on motoring to £1,525 million, and hence the share of petrol to 26.6% of total costs.
### TABLE 4

**U.K. Motor Spirit Prices at the Pump (Inner Zone).**

**Standard Petrol - Three Star from March 1967.**

( pence per gallon)

<table>
<thead>
<tr>
<th>Price at 1st January</th>
<th>Including tax</th>
<th>Tax</th>
<th>Excluding tax</th>
<th>Tax as percentage on price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1955</td>
<td>20.2</td>
<td>12.5</td>
<td>7.7</td>
<td>61.9</td>
</tr>
<tr>
<td>1956</td>
<td>20.4</td>
<td>12.5</td>
<td>7.9</td>
<td>61.3</td>
</tr>
<tr>
<td>1957</td>
<td>27.7</td>
<td>17.5</td>
<td>10.2</td>
<td>63.2</td>
</tr>
<tr>
<td>1958</td>
<td>21.1</td>
<td>12.5</td>
<td>8.6</td>
<td>59.2</td>
</tr>
<tr>
<td>1959</td>
<td>21.2</td>
<td>12.5</td>
<td>8.7</td>
<td>59.0</td>
</tr>
<tr>
<td>1960</td>
<td>21.2</td>
<td>12.5</td>
<td>8.7</td>
<td>59.0</td>
</tr>
<tr>
<td>1961</td>
<td>20.8</td>
<td>12.5</td>
<td>8.3</td>
<td>60.1</td>
</tr>
<tr>
<td>1962</td>
<td>22.1</td>
<td>13.7</td>
<td>8.3</td>
<td>62.0</td>
</tr>
<tr>
<td>1963</td>
<td>21.7</td>
<td>13.75</td>
<td>7.9</td>
<td>63.4</td>
</tr>
<tr>
<td>1964</td>
<td>21.7</td>
<td>13.75</td>
<td>7.9</td>
<td>63.4</td>
</tr>
<tr>
<td>1965</td>
<td>24.4</td>
<td>16.25</td>
<td>8.1</td>
<td>66.6</td>
</tr>
<tr>
<td>1966</td>
<td>24.4</td>
<td>16.25</td>
<td>8.1</td>
<td>66.6</td>
</tr>
<tr>
<td>1967</td>
<td>26.0</td>
<td>17.975</td>
<td>8.1</td>
<td>68.8</td>
</tr>
<tr>
<td>1968</td>
<td>26.9</td>
<td>17.975</td>
<td>9.0</td>
<td>66.5</td>
</tr>
<tr>
<td>1969</td>
<td>30.6</td>
<td>22.5</td>
<td>8.1</td>
<td>73.5</td>
</tr>
<tr>
<td>1970</td>
<td>31.5</td>
<td>22.5</td>
<td>9.0</td>
<td>71.4</td>
</tr>
<tr>
<td>1971</td>
<td>33.0</td>
<td>22.5</td>
<td>10.5</td>
<td>69.2</td>
</tr>
<tr>
<td>1972</td>
<td>33.5</td>
<td>22.5</td>
<td>11.0</td>
<td>67.2</td>
</tr>
<tr>
<td>1973</td>
<td>34.5</td>
<td>22.5</td>
<td>12.0</td>
<td>65.2</td>
</tr>
</tbody>
</table>

**Source:** The World Energy Outlook: A Survey, C. Robinson and Elizabeth Crook, September 1973, table 27.
According to the above source, the estimated total expenditure on motoring in 1962, broken down into its component parts, shows that running costs expenditure on each item is as follows (in £ millions)*.

<table>
<thead>
<tr>
<th>Item</th>
<th>Expenditure (£ millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol</td>
<td>405</td>
</tr>
<tr>
<td>Lubricants</td>
<td>25</td>
</tr>
<tr>
<td>Tyres</td>
<td>48</td>
</tr>
<tr>
<td>Maintenance and Repairs</td>
<td>200</td>
</tr>
<tr>
<td>Depreciation</td>
<td>382</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,060</strong></td>
</tr>
</tbody>
</table>

Supposing that the proportions remain constant over time, it follows that petrol expenditure accounts for at least 38 per cent of the running costs of a car if depreciation is assumed to constitute part of the running costs. But since depreciation depends partly on use and partly on the passage of time, the percentage share of petrol expenditure in running costs will obviously be higher, its upper limit being 60 per cent when depreciation is solely attributed to the age of a car. In fact this is an assumption made by Verleger and Sheehan who treated depreciation as falling into the fixed (standing) costs category."because it is more

* Similar estimates were made by the Road Research Laboratory for the years 1949, 1950, and 1960. Estimates of the total expenditure on private motoring are given in the annual 'Blue Books' on National Income and Expenditure.
a function of the car's age than of its use*.

These considerations indicate that petrol accounts for a large proportion of the variable costs of operating a car, which is an important point in deciding the variables on which the rate of utilisation of a car is assumed to depend (see chapter 5).

1.3.5 Storability

Another important feature of petrol, from the vast majority of consumers' point of view, is that it cannot be stored in considerable quantities. Deterioration of the product's quality and evaporation due to extended storage, on the one hand, and special storage facilities required because of the high inflammability of petrol on the other, makes storage uneconomical. The implication is that fluctuations in the quantity demanded of petrol due to price expectations are small, particularly in the short run. The average consumer reacts according to the price prevailing

* That was based on a conclusion by the Federal Highway Administration that 'depreciation is by far the greatest single cost of owning and operating an automobile, and in the great majority of cases, the age of the car is more important than its mileage in determining its resale or trade-in value'. See: P.K. Verleger, Jr. and D.P. Sheehan: 'The demand for gasoline', in D. Jorgenson (ed.): 'Econometric Studies of U.S. Energy Policy', North-Holland Publ. Co., 1977, p.p. 179 - 248.
at the time of purchase, bargaining or speculation about price movements being practically impossible*. In the long run, however, a reaction of the consumers to price increases seems possible in the form of a movement towards buying cars which are more economical in terms of petrol consumption.

1.3.6 Other characteristics of the U.K. petrol market

The existence of a large number of buyers and a small number of producing firms is also a point worth mentioning. From an economic point of view, lack of concentration on the demand side implies that influence of the prevailing price on the consumers' part is impossible.

On the supply side, the market is dominated by a few major companies, and it is characterised by a system of exclusive dealing in petrol retailing known as the 'solus system'. According to this system most distribution of petrol takes place through outlets selling only one brand. The question of whether absence of the solus system would lead to severe competition among companies is not an easy one to answer. Rapid expansion of crude oil production in the Middle East, re-entering of Russian oil into the world markets, the discovery by companies other than the majors of new sources of supply in Libya and Nigeria of high quality crude oil containing larger potential proportions of 'whiter' petroleum products and a fall in tanker freight-rates resulted in price reductions over the 1950s and 1960s.

* There is a small amount of speculation when prices are expected to rise.
On the other hand, the oligopolistic position of the major companies was significantly affected by developments that took place in the early 1960s. An inflow of independent firms or subsidiaries of foreign companies into the U.K. resulted in a shift of market share from the already operating majors to the new entrants. The latter were forced to buy or build their own stations so as to secure a slice in a market where the existing retailers were usually bound by long term solus contracts to the existing companies. However, this could only be achieved by the adoption of low prices and margins policy. Towards this purpose, cheap lots of petrol were initially imported from the Continent and this provided a means of breaking into the market. The result was a drop of the share of the five major groups (Shell Mex, BP, Esso, Texaco, Mobil and Petrofina), in terms of retail petrol stations supplied, from 94.4% in 1964 to about 79% in 1973 as table 5 shows. From the point of view of market share in terms of quantities of petrol sold, the losses of the majors as a group were even more significant; as it is shown in table 6, in the period 1964-1972 their share dropped by 15.3%.

The structural changes that took place in the 1960s may be attributed to several factors. To a certain, although not major, extent exogenous influences, such as monopoly policy, affected the degree of competition in the market. The financial agreements between major companies and retailers, often taking the form of long term low interest loans, and the length of 'solus' contracts, often in the
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group A</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shell Mex/B.P./National</td>
<td>18,792</td>
<td>17,650</td>
<td>15,500</td>
<td>14,550</td>
<td>13,220</td>
<td>12,700</td>
</tr>
<tr>
<td>Esso Cleveland Group</td>
<td>10,943</td>
<td>9,756</td>
<td>8,350</td>
<td>7,900</td>
<td>7,745</td>
<td>7,580</td>
</tr>
<tr>
<td>Texaco (Regent)</td>
<td>4,520</td>
<td>4,405</td>
<td>3,300</td>
<td>3,150</td>
<td>3,000</td>
<td>3,000</td>
</tr>
<tr>
<td>Mobil</td>
<td>1,984</td>
<td>1,500</td>
<td>1,500</td>
<td>1,500</td>
<td>1,500</td>
<td>1,450</td>
</tr>
<tr>
<td>Petrofina</td>
<td>1,604</td>
<td>1,400</td>
<td>1,350</td>
<td>1,320</td>
<td>1,300</td>
<td>1,250</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>37,843</td>
<td>34,711</td>
<td>30,060</td>
<td>28,420</td>
<td>26,745</td>
<td>25,980</td>
</tr>
<tr>
<td>% share</td>
<td>94.4</td>
<td>88.1</td>
<td>80.2</td>
<td>79.1</td>
<td>77.3</td>
<td>76.8</td>
</tr>
<tr>
<td><strong>Group B</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>321</td>
<td>630</td>
<td>800</td>
<td>800</td>
<td>300</td>
<td>800</td>
</tr>
<tr>
<td>Atlantic</td>
<td>-</td>
<td>50</td>
<td>410</td>
<td>454</td>
<td>477</td>
<td>443</td>
</tr>
<tr>
<td>Jet-Conoco</td>
<td>650</td>
<td>785</td>
<td>905</td>
<td>933</td>
<td>930</td>
<td>820</td>
</tr>
<tr>
<td>Isherwoods/Signal (VIP)</td>
<td>371</td>
<td>760</td>
<td>780</td>
<td>750</td>
<td>725</td>
<td>582</td>
</tr>
<tr>
<td>Amoco</td>
<td>17</td>
<td>172</td>
<td>360</td>
<td>369</td>
<td>355</td>
<td>345</td>
</tr>
<tr>
<td>Furco</td>
<td>89</td>
<td>448</td>
<td>590</td>
<td>346</td>
<td>361</td>
<td>379</td>
</tr>
<tr>
<td>Gulf</td>
<td>51</td>
<td>200</td>
<td>255</td>
<td>302</td>
<td>324</td>
<td>332</td>
</tr>
<tr>
<td>Burmah-Group</td>
<td>-</td>
<td>-</td>
<td>1,020</td>
<td>1,030</td>
<td>993</td>
<td>875</td>
</tr>
<tr>
<td>Tenneco</td>
<td>-</td>
<td>250</td>
<td>401</td>
<td>460</td>
<td>495</td>
<td>207</td>
</tr>
<tr>
<td>Imperial (I.C.I)</td>
<td>-</td>
<td>100</td>
<td>170</td>
<td>250</td>
<td>300</td>
<td>350</td>
</tr>
<tr>
<td>Chevron</td>
<td>-</td>
<td>95</td>
<td>160</td>
<td>185</td>
<td>200</td>
<td>213</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1,509</td>
<td>3,300</td>
<td>5,910</td>
<td>5,849</td>
<td>5,970</td>
<td>5,346</td>
</tr>
<tr>
<td>% share</td>
<td>3.7</td>
<td>8.5</td>
<td>15.8</td>
<td>16.2</td>
<td>17.1</td>
<td>16.1</td>
</tr>
<tr>
<td><strong>Group C</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small Independents Total</td>
<td>738</td>
<td>1,288</td>
<td>1,490</td>
<td>1,683</td>
<td>1,688</td>
<td>1,648</td>
</tr>
<tr>
<td>% share</td>
<td>1.8</td>
<td>3.4</td>
<td>4.0</td>
<td>4.8</td>
<td>5.6</td>
<td>5.1</td>
</tr>
<tr>
<td><strong>Overall Total</strong></td>
<td>40,090</td>
<td>39,399</td>
<td>37,473</td>
<td>35,952</td>
<td>34,595</td>
<td>32,974</td>
</tr>
</tbody>
</table>

TABLE 6

Market share estimates 1964 and 1972

<table>
<thead>
<tr>
<th>Group</th>
<th>Market share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1964</td>
</tr>
<tr>
<td>Group A</td>
<td></td>
</tr>
<tr>
<td>Shell Mex./BP/National</td>
<td>45.0</td>
</tr>
<tr>
<td>Esso</td>
<td>27.4</td>
</tr>
<tr>
<td>Mobil</td>
<td>5.9, 91.9</td>
</tr>
<tr>
<td>Texaco (Regent)</td>
<td>11.1</td>
</tr>
<tr>
<td>Fina</td>
<td>2.5</td>
</tr>
<tr>
<td>Group R</td>
<td></td>
</tr>
<tr>
<td>Jet/Conoco</td>
<td></td>
</tr>
<tr>
<td>V.I.P.</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Burmah</td>
<td>8.1, 2.0, 21.0</td>
</tr>
<tr>
<td>Chevron</td>
<td></td>
</tr>
<tr>
<td>Amoco</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td></td>
</tr>
<tr>
<td>Group C</td>
<td></td>
</tr>
</tbody>
</table>

neighbourhood of 20 years, were taken to constitute a barrier for new entrants resulting in a reduction of the degree of potential competition. This argument, opposing the companies' viewpoint that the solus system was a means to secure more efficient distribution and thus achieve economies of scale, resulted in a reduction of the maximum period of solus contracts to five years, after a report of the Monopolies Commission which investigated the petrol market supply conditions in 1964*.

The boom in the supply of crude during the 1960s and an unexpected increase in the demand for 'black' oil products resulted in an excess supply of petrol, thus creating entrance opportunities to independent marketers who were able to buy the desired quantities at low costs because of the crude surplus.

1.3.7 Conclusion

In summary, and according to what has been said previously, it appears that the price of petrol is likely to be a crucial factor in determining product demand arising from changes in the desired rate of car utilisation, given that it constitutes a considerable proportion of the variable motoring costs. It might also prove to affect long run demand: if, for example, petrol prices increase consumers may be induced to move towards smaller and more economical cars.

* Department of Prices and Consumer Protection: 'Petrol Prices', op. cit., p.8.
The supply conditions that prevailed between 1955 and 1973 with respect to the basic raw material (crude oil) and the flexibility of modern refineries in responding to different market conditions may be taken to indicate that against a relatively stable short run demand one may assume a highly elastic supply. This, along with other arguments advanced later, is important in assuming that derivation of price and income elasticities on the basis of a demand oriented analysis is permissible.
2.1 Demand Analysis

In this chapter a brief summary of some aspects of demand analysis is presented. This is necessitated by the following considerations:

First, it is believed that traditional theory should be the starting point of any empirical investigation of demand. In this way the limitations of static theory become obvious and the implications derived help the investigator in orienting his work towards more fruitful approaches as far as the explanatory power of the postulated reaction model is concerned. Secondly, the postulates of classical theory seem to underly explicitly or implicitly, most empirical work*.

Naturally, the purpose of the following discussion is not to examine in detail the theory of demand but rather to appraise its implications and relevance to applied work for an energy product.

The effects of prices and income on the demand for different products or services are the centres of interest of traditional economic theory. A large number of other

factors which are likely to influence the demand for a commodity is ignored, under the assumption of given preferences. Traditional theory tries to simplify the complexities of the real world by considering a consuming unit, which confronted by a finite set of prices, tries to maximise its satisfaction selecting an optimal combination of products that its limited income permits. The consumer, individual or household, is assumed to be making his choices within an extremely restricted framework where no stocks of goods are possessed, and price expectations or adjustments are neglected.

The process of utility maximisation leads to a system of n equations (one for each commodity) of the form:

$$q_{ij} = f_{ij}(p_1, \ldots, p_N, Y_j)$$

where $$i = 1, 2, \ldots, n$$

$$j = 1, 2, \ldots, N = \text{No of consumers}$$

each one of which expresses the quantity demanded of the relevant product or service ($$q_i$$) as a function of all money prices ($$p_i$$) and money income ($$Y$$). Consumer preferences determine the shape of the demand functions, which generally are assumed to have negative slopes*, indicating an inverse relationship between the quantity demanded of a product and its price, ceteris paribus.

* There are cases where the opposite relationship may hold (demonstrative consumption and Giffen goods) but these constitute exceptions rather than the rule.
2.2 From theory to applied demand analysis

The problems associated with the isolation and study of an equation referring to a specific commodity are enormous. The applied economist's task is to give some empirical substance to the postulates of demand theory, in terms of estimated price and income elasticities, within the context of \( n \) commodities and \( N \) consuming units. In actual terms \( n \) refers to a vast number of different products and brands, and \( N \) generally to millions of individuals or households. Obviously an attempt to insert all \( n \) prices into a demand equation would be an impossible task. Hence a number of restrictions on the demand function are called for. Otherwise, the number of parameters to be estimated would be far too great for the number of normally available observations, thus making empirical testing impossible.

Unfortunately, restrictions such as the negativity of the own-price substitution effect or that the demand function is homogeneous of degree zero (absence of money illusion) have little practical value. On the one hand, the net effect of an own-price change might be different from that expected ("inferior" goods case). On the other, non-consideration of all prices and income in single commodity studies limits the practical usefulness of the absence of money illusion restriction.

The second problem relates to the form in which the desired information is available. Normally, quantities consumed of individual commodities exist in the form of market aggregates, while the theory is expressed in terms
of a single individual or household. The passage from micro-theory to the investigation of market relationships raises the problem of aggregation, which in practical applications seems to have been neglected altogether. Of course, it is easy to set out conditions that permit investigation of aggregate relations but it is just as easy to think of conditions under which aggregation raises considerable problems. It seems then that "since we have no independent evidence about the issues involved there is not much point in repeated and prolonged speculation about these matters".*

Empirical research on demand, reflecting probably that the contribution of utility theory towards the specification of single commodity models is not considerable, has been carried out in terms of changes in income and a small number of prices of apparently related products. Some researchers have even ignored the direct influence of the prices of substitutes or complements and preferred to conduct their investigations in terms of changes in income and the product's own price only. This means that the effect of all other prices is summarised in the form of a general price index which, in turn, is used either as a separate variable** or


As a deflator in order to express income and the product's own price in real terms*.

As for the appropriate mathematical form of the function, it is selected on a "relatively better fit" basis, since at this point the theory is quite helpless. While "At best, economic theory can specify what conceptual variables appear in an equation, and sometimes certain homogeneity properties of the equation, and perhaps something about the algebraic signs and sizes of certain partial derivatives ... we often do not learn whether the function is linear in real income and relative prices, or linear in their logarithms, or quadratic or exponential, or of some other form"**.

2.3 Applied Demand Analysis: Recent Developments

Despite the limited usefulness of utility theory in practical situations, attempts have been made towards the estimation of complete equation systems of demand, through the utilization of theoretical implications.

The models so constructed assume, as the theory requires,

* For the appropriateness of using it as a deflator see: A. Brown and A. Deaton, op. cit. p. 184

that the demand for each commodity depends on all prices and income (or total expenditure). A number of theoretical restrictions is subsequently imposed that are still unable to solve the problem of the number of observations being less than the number of parameters to be estimated*.

* For example:

(i) the obvious restriction

$$\sum P_i Q_i = TE \text{ (or } Y)$$

(where $P$, $Q$, $TE$ (or $Y$) represent price, quantity and total expenditure (or income) respectively) which requires that the sum of expenditures on each commodity be equal to total expenditure or income.

(ii) $\frac{\partial}{\partial p_i} (\partial Q_i / \partial Y) = 1$, which is the outcome of the differentiation of the previous restriction with respect to income, constraining the income slopes.

(iii) The zero homogeneity restriction

$$Y(\partial Q_i / \partial Y) + \sum_{j=1}^{2} P_j (\partial Q_i / \partial P_j) = 0$$

stating that if income and all prices change by equal proportions, demand is unaffected, or alternatively that the sum of all price elasticities and income elasticity is equal to zero.

(iv) A further $n(n-1) \div 2$ restrictions are provided by the Slutsky symmetry conditions, stating that

$$S_{ij} = S_{ji}$$

where $S_{ij}$ stands for the substitution effect for the $i^{th}$ commodity with respect to the $j^{th}$ commodity's price.
A solution is achieved from an additional set of rather severe a priori restrictions relating to the nature of the utility function*. These, have their origins in the neo-

* Known as assumptions of:

Of the above, the first assumption has been widely used compared to the other three, although it implies that the marginal utility of any commodity included in the system is not affected by the quantity consumed of any of the remaining products, that is the marginal utility of commodity i is a function of q_i only. Clearly such an assumption is reasonable (but still not very realistic) only when different products are grouped into a number of 'independent' categories. But then such a grouping has to be decided on the basis of a generally accepted framework. Otherwise doubts might arise as to whether categories such as 'transport' and 'entertainment' may be treated as products whose utilities are totally independent.
classical demand theory which may not provide a realistic
description of actual market demand behaviour, particularly
with respect to durable goods or products that are technolo-
logically linked with durables such as motor spirit.

However, although the estimation of complete demand
systems is most appealing, their use is limited because of
the following difficulties and underlying assumptions:

1. The investigator does not have the freedom to choose
   for each particular equation the mathematical form that
   best fits the data. For practical reasons the form of
   all equations should be the same, and normally a linear
   approximation is employed, as satisfying the condition
   which requires that the sum of individual expenditures
   be equal to total expenditure or income. However, the
   performance of the linear form, as most single commodity
   studies have shown, has been fairly poor. Therefore,
   the explanatory as well as predictive power of the
   models on which this form is imposed is likely to be
   poor.

2. Although the complete demand systems approach has the
   advantage that the whole set of cross elasticities of
   demand may be taken into account, it entails the
   sacrifice of considerable information relating to
   specific markets and commodities.

3. Any question relating to the simultaneous equation
   problem is completely ignored. More specifically,
   since all commodities (grouped in broad categories)
   are included, it seems reasonable that there is a feed-
   back from expenditure to income. However, while for
individual demand equations this feedback might be negligible, in the case of complete systems this, obviously, does not seem to be justified.

2.4 Pragmatic orientation of empirical demand studies

The previous brief exposition seems to indicate that given the limitations mentioned, it is up to the student of a particular market or commodity to use single or system models. It is important, however, that this choice be made on the basis of the purpose of the research as well as practical considerations. It is mainly the latter which led to the "pragmatic" approach to the theory of demand that characterises most empirical investigations. The followers of it

"accepted the fundamental 'law of demand' on trust, and formulated demand functions directly on the basis of market data without reference to the theory of utility and the behaviour of the individual consumer ..............

Such demand functions refer obviously to the market behaviour of the consumers, that is, to the behaviour of all consumers as a group, and not to the behaviour of single individuals"*.

However, a pragmatic approach to demand problems should be the outcome of a process based on a rational framework. Otherwise one might end up with formulations where variables, 

whose relevance or qualitative effect is questionable, are introduced in order to achieve a "better" explanation of the phenomenon being studied. The reader will be able to assess the validity of this argument in the following chapter which is devoted to a review of a number of studies on the demand for motor spirit.*

What has been said previously, raises the important question of methodology in empirical research. The view adopted in this study is briefly outlined below.

2.5 **The Model Building Approach**

The approach used in this study is that of constructing hypotheses and testing them by statistical means. Every hypothesis takes the form of an econometric model which is confronted with available information in order to evaluate the degree of agreement between the "theory" and the actual process of events. In doing so one implicitly refuses over-attachment to a specific hypothesis. However, this seems to be an objective way of trying to understand the complexities of the real world. If it is true that

"we all have a natural tendency to hold on to our own theories longer than we should and we are not always as objective as we should be in testing them"**

---

* or motor gasoline as it is called in American Studies.

** C. Robinson op. cit., p.4 onwards where an outline of the advantages of the Model Building Approach is given.
a method of analysis should be followed that allows sufficient flexibility. It is believed that the approach adopted in this study not only allows such flexibility but, as long as there is an element of consistency between different model formulations, is the only way that permits learning from experience. (See ** p. 45 )

The above method seems to be a reasonable one if one considers a problem imposed by the type of information available. Ideally, one should test a hypothesis using data which have been collected for the specific purpose. In practice, information is used that has been gathered for various reasons. Thus, in most empirical studies it is not the ideal data but the best substitute for it that is used.

However, testing different hypotheses through the use of the same set of data involves two dangers. First, if different formulations of a process appear reasonable and according to some criterion, the one that "fits the data best" is selected,

"the classical statistical inference procedures do not apply to those same data without some adjustment. This is because these classical procedures assume that the maintained hypothesis ... is known with certainty, whereas in the experimental procedure (implied by the approach adopted in this study) ... the "maintained hypothesis" is not known with certainty, but is chosen because it fits the data better than the
other maintained hypotheses... The effect is essentially as if a systematic non-random factor were introduced into the process for selecting samples, that is, as if only those samples that fit the data unusually well were used"*.

The second danger is related to the previous one,

"it concerns the problem of how we decide when to stop hunting for additional maintained hypotheses to try out experimentally against the data ... If an economist is clever enough or persistent enough, he can always find an equation that fits the available data fairly well; he may also convince himself that it is a theoretically reasonable equation. The danger lies in the possibility of being too clever or too persistent, and finding an equation that fits the available data well enough but is nevertheless wrong because it describes temporary or accidental features of the available data, rather than the enduring systematic features"*.

In order partly to overcome these difficulties the hypotheses formulated were confronted by additional data where this was possible.

From the point of view of the type of data used, demand

studies in general rely either on cross-sectional data, time series data, or a combination of both. In this study the emphasis was on time series data, for the following reasons. First, derivation of price elasticities through the use of family budget surveys is not possible. This type of data usually refers to a single point in time and the assumption has to be made that all consuming units face an identical price. Second, family budget data do not permit in all cases investigation of the total demand for a product. Apart from private motoring, petrol is used for commercial and business purposes as well and hence the information obtained from budget surveys is inferior to the information recorded in the form of time series. Nevertheless, by using cross-sectional data one overcomes a serious problem. Since the validity of the cross-section approach does not depend on the influence of probable shifts in the relationship under investigation the problem of identification does not arise.

The use of time series data does offer the advantage that investigation of the total demand for a product, regardless of its use, may be carried out, but it raises the question of legitimacy of a single equation demand model, an answer to which for the specific case of petrol is attempted below.

2.6 Legitimacy of a Demand Oriented Model

The question of whether a single equation model may be used for the investigation of the demand for any product, using time series data is related to the difficulty of statistically deducing out of a set of relationships which constitute a model, the parameters associated with the
structural equation of interest (demand function in this case). This happens because the available information (time series data) refers to points of intersection of unknown functional relationships. Thus, without information concerning the identifiability of a relationship which, due to the nature of economic phenomena inevitably belongs to an interdependent system of equations, no further progress may be made. From the point of view of estimation, use of ordinary least squares methods may lead to unreliable estimates.

In empirical investigations the identification problem is a quite serious one and clearly a general agreement has not yet been reached as to the validity of studies that do not explicitly take the problem into account. Some economists* have demonstrated that empirical estimates of non-identified parameters are quite useless; others have expressed the view that "situations do exist in which single equation least squares methods are naturally called for by the stochastic, economic theoretical, and institutional nature of the relationship being considered;** a third group are satisfied as regards the significance of specified


demand curves and results derived. The great number of studies concerning the demand for different products is perhaps an indicator of preferences and tendencies.

However, accumulated empirical work is not by itself a reason for overlooking the serious implications that may arise when the identification condition is not examined. Fortunately, there are cases where a regression of quantity and other variables gives a consistent estimator of demand. This happens when there are reasons to believe that supply is independent of current price. Such an assumption seems plausible in the case of petrol for the following reasons:

Price may be considered as a purely endogenous variable within a competitive market, as in classical theory. In this rather rare situation, the equilibrium price that clears the market is the outcome of the interaction of desired demand and desired supply. In the ideal competitive market, the main operating forces are endogenous. In the market for petrol, other factors play an equally if not more important role in the formulation of the price prevailing during a certain period. Consider, for example, the price of a unit (gallon) of petrol. This may be roughly divided into:

1. The value of raw material (mainly crude oil) necessary for the production of a unit of the product.
2. The amount of tax imposed by the authorities on every gallon of petrol. (In the U.K. the tax rate ranged from 59 to 73.5%, during the period 1955-73, as may be seen from table 4.)
3. Other unit costs and profits.
Now, the price of raw material (crude oil) is being decided in world markets; the amount of tax imposed may also be taken as 'exogenously' given. Since these two parts constitute the major proportion of the final market price of petrol, one may validly assume that the price of petrol may be thought of as an exogenous variable determined outside a supply - demand system. Furthermore, the pricing policy of the oil companies in what is effectively an administered price market, is to set price for a period ahead: supply is highly elastic at the predetermined price. Further support of this argument can be sought by considering the nature of the oil industry which requires high levels of fixed investment at all levels of activity such as extraction, transportation, research, marketing and distribution. The current price of a product may not be of great importance in determining supply in an industry of this kind. It is rather long run considerations (concerning labour and capital markets, technology, future prices of raw materials and so on) that are likely to be of prime importance when supply decisions are undertaken.

In summary, it may be concluded that derivation of empirical estimates, relating to the demand function for petrol, by neglecting the supply side of the market is legitimate, or at least not misleading. This is because

"Partial equilibrium analysis based on fitting single equations requires, ideally, a homogeneous commodity with a single quantity dimension, stable consumer
preferences, and relatively large fluctuations or trends in supply which are independent of the current market price"*.

The arguments advanced previously support the view that these conditions are closely met in the case of petrol.

2.7 Demand for Petrol: A First Approximation

According to what has been previously said, an investigation of petrol demand within a 'price-income' framework would seem an obvious starting point**. This is by no means the most satisfactory model to test empirically. It simply represents a first approximation to the postulates of traditional static demand theory that will allow identification of some of the problems of model-building in the petrol market.

Demand for petrol is considered here as a function of its own price and real disposable income. The function was defined both at per capita and at market levels for reasons explained later.

* A. Brown and A. Deaton, op. cit. p. 179

** One may validly argue that inclusion of other variables such as the price of cars, or prices of alternative forms of transport would constitute a better approximation. This, however, would create some problems of estimation and interpretation. Estimation problems would arise because of the tendency of the relevant variables to move together over time. Lack of independent variation/
2.8 Per Capita Demand for Petrol: Definition of Variables

Under such a formulation the dependent variable \( (Q_t/P)_t \) is defined as total petrol demand expressed in \( 10^6 \) gallons \( (Q_t)_{t} \), divided by home population \( (P_t) \). Since in the official statistics the quantity of petrol demanded is expressed in thousand tons, conversion factors that were different from period to period were used.

The relative price series \( (PG)_{t} \) was compiled from unpublished information relating to the price history of petrol, provided by British Petroleum. This shows all changes in price for the four different grades (Best, Premium, Economy, Ordinary) during the period 1955-1973. On the basis of this information an annual weighted average for every grade was at first constructed using the time periods during which a particular price was prevailing as the variation (multicollinearity) would then prevent the separation of the influence of each particular independent variable. Problems of interpretation would arise because a single equation model is likely to provide a poor description of the underlying processes. A drastic change in car prices, for example, will certainly have an influence on petrol demand. But this influence will be an indirect one. It will manifest itself through a change in the stock of cars that the community desires to hold. Thus, it would seem more appropriate to try to describe these processes in a more satisfactory way. This is attempted in subsequent chapters. At this stage the overall influence of all other prices is supposed to be taken into account by a general price index which is used as a deflator.
relevant weights. After the compilation of these annual averages for every grade, an overall weighted annual average petrol price was obtained where the annual quantities of the particular grades were used as weights. An example at the end of this section illustrates the procedure adopted (tables 7 and 8).

Variable (YPK) is defined as per capita real disposable income and it is the ratio of total real disposable income \((Y)_t\) divided by home population \((P)_t\).

The consumers' price index was used in order to transform current into constant (1970) prices.

All variables along with the relevant sources are presented in detail in the Data Appendix.

**Calculation of the Annual Average Price of Petrol: An Example**

We have at our disposal the prices of each grade of petrol for both the retail and commercial/industrial markets, the dates of price change (table 7) and a classification of quantities consumed of petrol according to market and grade (table 8).

On the basis of the information provided in table 7, one may calculate the average prevailing price of each grade in each particular market, as follows:

**Retail Market**

Weighted average price for Best = \((36.72 \times 113 + 37.82 \times 160 + 38.92 \times 71 + 43.00 \times 16) \div 360\)

= 37.92 \((= P_1)\)

" " " " Premium = 37.11 \((= P_2)\)
# TABLE 7

**PETROL PRICE HISTORY: 1973**

(All prices in pence/gallon)

<table>
<thead>
<tr>
<th>Date of price change</th>
<th>Grade*</th>
<th>Retail Market</th>
<th>Commercial-Industrial Market</th>
<th>Period of Applicability (in days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Best</td>
<td>Premium</td>
<td>Economy</td>
</tr>
<tr>
<td>1/1/73</td>
<td></td>
<td>36.72</td>
<td>35.92</td>
<td>35.00</td>
</tr>
<tr>
<td>24/4/73</td>
<td></td>
<td>37.82</td>
<td>37.02</td>
<td>35.10</td>
</tr>
<tr>
<td>4/10/73</td>
<td></td>
<td>38.92</td>
<td>39.12</td>
<td>37.20</td>
</tr>
<tr>
<td>15/12 - 1/1/74</td>
<td></td>
<td>43.00</td>
<td>42.00</td>
<td>41.00</td>
</tr>
</tbody>
</table>

* The above grades were taken to correspond to 5, 4, 3, and 2 "star" a classification introduced in 1967. Before 1967, grades were Best (5 Star), Premium (3 and 4 Star) and Standard (2 Star). See Digest of U.K. Energy Statistics 1975, table 43.

** A 30-day month has been assumed.
Weighted average price for Economy = 36.19 (= $P_3$)
" " " " Ordinary = 35.71 (= $P_4$)

**Commercial-Industrial Market**

Weighted average price for Best = 36.31 (= $P_5$)
" " " " Premium = 35.59 (= $P_6$)
" " " " Economy = 34.65 (= $P_7$)
" " " " Ordinary = 33.71 (= $P_8$)

Now, dissagregation of total quantity of petrol consumed according to market and grades shows that the situation in 1973 was as follows:

**Table 8**

Classification of quantities consumed of petrol (in thousand tons) according to market and grade: U.K. 1973

<table>
<thead>
<tr>
<th></th>
<th>Grade</th>
<th>Market</th>
<th>Best</th>
<th>Premium</th>
<th>Economy</th>
<th>Ordinary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retail</td>
<td>q_1=2627</td>
<td>q_2=8119</td>
<td>q_3=2001</td>
<td>q_4=2948</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial</td>
<td>q_5=145</td>
<td>q_6=464</td>
<td>q_7=92</td>
<td>q_8=263</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Accordingly, the overall annual average price of petrol for 1973 is given by:

$$\bar{P}_{1973} = \frac{\sum_{i=1}^{8} P_i q_i}{\sum q_i} \quad \text{for } i = 1, \ldots, 8$$

$$= 36.763 \text{ pence/gallon}$$

The prices for all years were compiled similarly.
2.9 Per Capita Demand for Petrol: Regression Results

The per capita demand equation was estimated on the basis of annual data, referring to the U.K., and covering the period 1955-1973. Two mathematical forms, linear and linear in logarithms, were tried with the variables defined as deviations from their observed mean values*. The ordinary least squares (OLS) estimates of the parameters obtained, are presented in tables 9 and 10.

---

* Note that by defining the variables in deviations from their means, one obtains estimates of the slopes (derivatives in the linear case and constant elasticities in the double-logarithmic case). Estimation of the intercept of the function \( \hat{\beta}_0 \) is then a matter of simple substitution into the formula

\[
\hat{\beta}_0 = \bar{Y} - \sum_{i=1}^{n} \hat{\beta}_i \bar{X}_i
\]

where \( \bar{Y} \) stands for the mean value of the dependent variable, \( \bar{X}_i \)'s stand for the mean values of the Independent variables and the \( \hat{\beta}_i \)'s refer to the estimated slopes.
### Table 9


\[
(\frac{Q_t}{p_t}) = a_1 P G_t + a_2 (YPK)_t + u_t
\]

(Variables defined in deviation from their means)

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Estimates</th>
<th>t-statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.48</td>
<td>(2.174)</td>
</tr>
<tr>
<td></td>
<td>.26</td>
<td>(12.097)</td>
</tr>
</tbody>
</table>

\[ R^2 = .967 \]

D-W statistic = 1.436

### Table 10


\[
(\frac{Q_t}{p}) = b_1 (PG)_t + b_2 (YPK)_t + u_t
\]

(Variables defined in deviation from their means)

<table>
<thead>
<tr>
<th>Coefficients/elasticities</th>
<th>Estimates</th>
<th>t-statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>.644</td>
<td>(1.461)</td>
</tr>
<tr>
<td></td>
<td>2.411</td>
<td>(10.546)</td>
</tr>
</tbody>
</table>

\[ R^2 = .965 \]

D-W statistic = 1.45

---

* primes denote logarithms (base e).
2.10 Evaluation of the Estimates

Before any attempt is made to evaluate the regression estimates it seems appropriate to give an outline of the criteria used. Briefly, these may be classified as follows:

1. Economic a priori criteria, relating mainly to the signs of the regression coefficients.

2. Statistical criteria, relating to the statistical reliability of the estimates. These are:

   The t-statistic, that is the ratio of the estimate of a parameter to its standard error. Customarily, the value of this ratio is compared with tabulated theoretical values (according to the available degrees of freedom and the desired - normally 5% - level of significance). A coefficient is considered to be statistically significant at 5% if it is at least twice the size of its standard error, but this is not always necessary. The 'two-tail' test, described above, should be used if one wants to test whether an estimated coefficient is significantly different from zero; but if on the basis of a priori economic criteria one expects a coefficient to have a specific sign, then it is the 'one-tail' test which is applicable*. Since economic theory postulates that income, for instance, is expected to be positively related with the quantity demanded of a product, what one has to test is whether this

coefficient is statistically greater than zero as opposed to different from zero (which includes the possibility of it being negative).

As for the explanatory power of the independent variables selected, the coefficient of multiple determination, \( R^2 \), is used. Nevertheless, too much importance is not attached to a high value of \( R^2 \), since a high \( R^2 \), although desirable, is not always a satisfactory indicator of the explanatory power of a set of variables. Dealing with time series, in particular, a high \( R^2 \) might just reflect the fact that all economic variables tend to move together over time (as have consumption of petrol and disposable income). However, as Fisher and Kaysen have pointed out:

"such correlations generally have little analytical value... (being) incapable of indicating possible changes in the rates at which one set of variables will move relative to another"*.

3. Econometric criteria, relating mainly to the problems of autocorrelation and multicollinearity. The standard Durbin-Watson "d" statistic is used for the examination of the randomness of the regression residuals. Detection of autocorrelation necessitates some kind of corrective action and in empirical work transformation of the variables into first differences is a solution often adopted. In this study the view is taken that "the

---

type of corrective action in each particular econometric application depends on the cause or source of autocorrelation".* This implies that it seems more appropriate to try first to improve a model by considering variables that have possibly been left out of the analysis than to resort to mathematical transformations without examining probable errors of model specification.

About multicollinearity very little may be said: it is a data deficiency problem for which there exists no known solution**. The ill effects of multicollinearity show up in the form of large standard errors of the regression estimates which are thus rendered statistically insignificant, in contradiction to a priori expectations. One corrective action in such a case would be to drop from the estimating equation the relevant variable. This procedure is adopted here when necessary***.


*** Combination of cross-section and time series observations is a procedure also used. However, due to data limitations, which become acute particularly when the naïve 'price-income' model is abandoned, is not possible.
Consideration now of the estimates derived, on the basis of the criteria outlined above*, shows that as far as the price coefficient is concerned, the results are poor. On theoretical grounds one would expect that the 'average' consumer reacts inversely to a price change, and not in the same direction as the derived coefficients indicate. The income coefficient, on the other hand, is highly significant and with a positive sign, as one would expect on a priori grounds. However, its size seems unreasonably high. In the double logarithmic case, for instance, where it gives a direct estimate of the corresponding elasticity it would indicate that a 1% increase in per capita income will be followed by a 2.4% increase in quantity demanded of petrol. However, it is hard to see why, 'other things remaining constant', as this model assumes, the income elasticity is so high. It is most probable that the income coefficient represents the sum of several effects. In other words, an increase in disposable income might influence the amount of petrol that motorists use (which in turn reflects an increase in the rate of utilization of the stock of cars in the community). This may be called 'the direct effect'. On the other hand, an increase in income may influence demand indirectly - the 'indirect effect' - through an increase in the number of petrol powered motor vehicles.

* The same criteria are used throughout the study. In one particular formulation (use of lagged dependent variable as an explanatory factor) the Durbin-Watson statistic is not applicable (see chapter 5).
Another equally important explanation may be offered as a probable reason for the poor performance of the per capita equation. Transformations of variables may assume relationships that in fact do not exist and the procedure of dividing total consumption by total population, in particular, is not altogether satisfactory. First, the number of consumers most likely differs according to the commodity under study— for instance, in the case of petrol, legislation imposes a lower age limit on the right to drive. Thus, while a higher than normal increase of the population might not have any effect on the demand for private transportation, it will certainly affect a time series expressed in per capita terms. So if the proportion of persons under a certain age in the community does not remain constant, the use of total population as a divisor is likely to produce per head figures that are not only misleading in absolute amount but are also inaccurate in their movement over time. Different combinations of ages (and sexes) can be used to provide useful estimates for different commodities on a per head basis, and in several studies* a weighted sum of the numbers of males and females of different ages in the community is used. This weighting is not adopted here. Instead the regression equations are redefined at the market level, using total consumption \( Q_T \) and total income \( Y \).

Under such a formulation the 'price-income' model estimates are as follows (tables 11 and 12):

**Table 11**

Market Demand for Petrol - Linear form

\[(Q_T)_t = a_1 PG_t + a_2 Y_t + u_t\]

(Variables defined in deviations from their means)

<table>
<thead>
<tr>
<th>Parameter estimates</th>
<th>(a_1)</th>
<th>(a_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>t-statistics</td>
<td>(2.486)</td>
<td>(14.754)</td>
</tr>
<tr>
<td>(R^2)</td>
<td>.977</td>
<td></td>
</tr>
<tr>
<td>D-W statistic</td>
<td>1.55</td>
<td></td>
</tr>
</tbody>
</table>

**Table 12**

Market Demand for Petrol - Double log form

\[(Q_T)_t = b_1 (PG)_t + b_2 Y_t + u_t\]

(Variables defined in deviations from their means)

<table>
<thead>
<tr>
<th>Parameter estimates</th>
<th>(b_1)</th>
<th>(b_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>t-statistics</td>
<td>(1.534)</td>
<td>(12.767)</td>
</tr>
<tr>
<td>(R^2)</td>
<td>.975</td>
<td></td>
</tr>
<tr>
<td>D-W statistic</td>
<td>1.53</td>
<td></td>
</tr>
</tbody>
</table>
The performance of the market demand equations does not show any improvement compared to the per capita formulations, as may be seen from the price coefficients which still exhibit unexpected positive signs. The income elasticity continues to be unreasonably high giving the impression that this variable becomes a 'portmanteau' for all underlying changes, not explicitly accounted for by the naive formulation. Furthermore, the similarity of the results with respect to the signs of the price coefficients tends to indicate that it is not the mathematical form but rather the specification of the relationships which is unsuccessful. This suggests that attention should be focused on factors that in a simple price-income model are ignored, or assumed to remain constant. In chapter 1 the strong technological relationship or, more properly, technological complementarity between cars and petrol was stressed. This, in conjunction with the explanation given about the unreasonably high income elasticity obtained, suggests consideration of a 'stock' or 'indirect income' effect. In subsequent chapters a more pragmatic approach to problems of demand analysis is adopted where intuitive reasoning is used rather than preconceptions about utility maximising consumers. Before the formulation of models that are designed to fit observed market behaviour, however, a review of studies on the demand for petrol is presented in the following chapter to show how other workers in this field have treated the problem.
Chapter 3

Literature Review

3.1 Introduction

A review of a number of studies of the demand for petrol shows that the formulations of the models differ with respect to the theoretical restrictions used as well as the estimation techniques employed. Nevertheless, such a review helps the research worker to draw conclusions as to the validity of assumptions made, theoretical or practical foundations of the models constructed, and data requirements. Besides, the (implicit or explicit) claim of the student of a particular market that his model constitutes an improvement compared to previous work can be more easily assessed.

The studies considered refer neither to the same period nor to the same country; therefore, one expects that differences in models and results will reflect differences in market structures and other related economic or non-economic factors. Nevertheless, they suggest that some general conclusions can be drawn.

Research referring to motor gasoline demand can be classified into two main categories:

(i) Engineering type, where relationships between fuel economy and vehicle characteristics are analysed; and

(ii) Econometric type, where attention is focused on the influence of economic, social and
demographic variables, such as prices, income, population, lagged consumption, etc., on variations in the quantity demanded of the product.

In what follows, an engineering type of study is first presented which concentrates on motor vehicle characteristics; the discussion is then turned to econometric research. The common feature of the latter type of study is its failure to utilise the kind of data found in the work by Hill and Yudow (the engineering type of study). This is an important point which is taken up in chapter 4.

3.2 C.T. Hill and B.D. Yudow Study*

This is an engineering type of study referring to the USA. The model is based on readily identifiable characteristics of the automobile population, such as average vehicle weight for each model year during the period 1954-1971, average pound-miles per gallon, derived from a relationship between fuel economy and vehicle weight**, and total sales.

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** This relationship has been developed by the U.S. Environmental Protection Agency (EPA) and expresses the amount of fuel consumed per mile (F/M) as a linear function of the auto weight (W), that is: 

\[(F/M) = \frac{1}{\text{constant}} - kW\]
A combination of these factors with data on the lifespan of automobiles and data from a survey on miles driven per car as a function of age, gives an engineering estimate of gasoline consumption. Assuming the lifespan of automobiles and the miles driven constant, they derive conditional forecasts from 1972 to 1980 under different assumptions referring to the 'c' factor (see footnote), annual car sales, and average weight of vehicles sold. They give a forecast of gasoline consumption for 1980 ranging from a 10% decrease to a 65% increase relative to 1973. The 'low' forecast is based on the assumption that the average car weight during the period 1974-1980 will be 2869 pounds against an average of 3339 pounds in 1971, that there will be a decline in the annual average growth rate of car sales from 3.4% in 1973-74 to 1.7% during 1975-80, and that the 'c' factor will be 30% higher than its 1973 level. The 'high' forecast is the outcome of assuming unchanged sales growth rate and average car weight, and a 30% decrease of the 'c' factor compared to its 1973 level.

The lack of consideration of the likely influence of economic factors is one of the undesirable features of the

\[
\frac{f}{M} = \frac{1.0}{c} 
\]  \hspace{1cm} (3.2.1)

where c is a constant obtained by least squares regressions for each of the years 1957-1973. See: USA Environmental Protection Agency: 'Fuel Economy and Emission Control', November 1972.
model if it is to be used in a period of rather significant petrol price increases. This drawback is recognised by the authors who conclude that "more work should be done on this and similar models".

3.3 Kitchell Study*

E. Kitchell, using multiple regression analysis, combines trend ratios of consumption per vehicle, real price of motor gasoline, and real income to derive "the statistical law" of demand for motor fuel in the United States, 1929-1957. Such an approach assumes that the consumer has a knowledge of the "normal" (or trend) level of economic variables, namely consumption, prices and income, and that this "normal" changes smoothly through time. Now, since the investigator does not have an a priori knowledge of these "normal" levels during a specific period, he tries to approximate them by fitting empirical curves to the data. Once the comparatively long-term movements are removed, the so isolated short-run movements may be further studied.

Kitchell makes the above hypothesis operational by fitting least squares straight line trends to the logarithms of the data on motor fuel consumption per vehicle \(x_1\), real price of gasoline in cents per gallon \(x_2\) and per capita

real income in dollars ($x_3$). Subsequently, the ratios of the actual values of these variables in period $t$ to the corresponding theoretical time trend value in $t$ (denoted by $X_1$, $X_2$, and $X_3$ respectively) are used in the regression analyses for the derivation of the demand functions and the relevant price and income elasticities.

The multiple regression equation expressed in ratios is as follows:

$$X_1 = 92.429 - 0.02506 X_2 + 0.10196 X_3 \quad (3.3.1)$$

Now, given that by definition $X_i = \frac{X_i}{T_i}$ (where $i = 1, 2, 3$ and $T_i$ denotes the theoretical trend values of the corresponding series), one may transform equation (3.3.1) into

$$x_1 = 92.429(T_{x_1}) - 0.02506 \frac{T_{x_1}}{T_{x_2}} x_2 + 0.10196 \frac{T_{x_1}}{T_{x_3}} x_3 \quad (3.3.2)$$

However, the usefulness of the study is limited for the following reasons:

Although the results reported imply very low elasticity values for price (ranging from $-0.101$ to $-0.071$) and income (ranging from $0.081$ to $0.152$) their significance cannot be evaluated since the author does not apply any statistical criteria to test whether the derived coefficients are different from zero. Note also, that the definition of the dependent variable (consumption per motor vehicle) is far from accurate. Domestic demand is defined as production plus imports, minus exports, plus or minus the change in

* E. Kitchell, p.29.
stocks, but no allowance is made for the fact that this series includes aviation gasoline. On the grounds that 'aviation gasoline is usually less than one-eleventh of the domestic consumption of motor fuel, domestic demand for motor fuel is assumed to be determined by the automotive demand'*. Moreover, the number of motor vehicles in use is approximated by the sum of passenger cars, taxis, motor trucks and buses, registered during a certain period; but 'even though a bus or a motor truck consumes much more gasoline than a passenger car!'** no adjustment was made for this. Finally, a regression of consumption \((x_1)\) on, among other variables, the trend values of the consumption series \((Tx_1)\), seems to be an attempt to explain variations in the dependent variable in terms of the dependent variable itself, which is clearly an inconsistency.

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* E. Kitchell, p.18.

** E. Kitchell, p.18
3.4 Cangelosi Study*

Cangelosi considers the demand for gasoline in four states - Montana, North Dakota, Colorado, and Washington as well as USA as a whole - for the period 1946-1959 in an attempt to provide a framework for forecasting purposes. Thus simple time trend and regression analysis are used and projections are made on the basis of the parameter estimates obtained from the sample period.

There is no need to elaborate on the first method employed. The author himself admits that "within a limited time period a recognizable trend may exist, but it is hardly possible for any sociological or economic data to move infinitely in the same direction at the same rate"**.

The way he uses regression methods, however, deserves some scrutiny. First the factors to be considered are chosen according to two criteria:

1. A relatively high degree of correlation between the dependent and each of the explanatory variables, and
2. Easier predictability of the explanatory than the dependent variable.

Some of the selected explanatory factors are: motor vehicle registration, automobiles per person, travel by


motor-trucks in vehicle - miles and travel by all vehicles, persons per automobile, Federal Highway Aid and the average price of gasoline per gallon. Each of the above mentioned factors is in turn tested and the relevant correlation coefficient is calculated. Tests concerning the statistical significance of the parameters or the existence of autocorrelation are completely ignored. Apart from these shortcomings, however, one wonders why factors such as "Motor vehicle registration", "Federal Highway Aid", etc., are considered as "more predictable" than gasoline consumption. Clearly, such an assumption is very unrealistic. It is also interesting to note that price is rejected as a variable which is likely to affect total demand on the grounds that "both money and real price of gasoline per gallon gave a high and positive R". Again, this conclusion is reached by separately correlating total quantity of gasoline with money price and then with real price. When he considers total demand as a multivariate relationship further trouble arises. Now eleven explanatory variables are tested simultaneously against quantity demanded. Naturally one would not expect to obtain satisfactory estimates with only 1 (1) degree of freedom (that is 13 observations and 12 variables including the constant term). Indeed, this is the case. The signs of the coefficients are different for different states. As an example, we mention real personal income which was found to have a positive effect in the cases of Montana and Colorado and a negative effect for Washington, North Dakota and U.S.A. as a whole. The same happens with almost all coefficients.
A probable explanation could be that most of them are statistically equal to zero and therefore their sign is not of any importance. This cannot be examined though since the author does not report the standard errors associated with the coefficients. Instead he reports that the coefficients of multiple correlation range between .9978 (North Dakota) and .999 (Washington and U.S.A.). Nevertheless, he points out that "under any circumstances these coefficients may seem to indicate very high degree of correlation, but there are too few degrees of freedom relative to the number of observations to attach much significance to the coefficients"*. Unfortunately, a similar conclusion seems to be valid for the study as a whole.

3.5 **Broome Study**

The purpose of Broome's study is the statistical investigation of the elasticities of demand for gasoline in Alabama. The variables selected for inclusion in the demand function were:

1. The per capita consumption of gasoline;
2. The price of gasoline at Birmingham (arithmetic average of the retail price of regular grade at Texaco stations on the first of each month);
3. The change in the general price level;

* V. Cangelosi, op. cit., p.155.

** C. Broome, op. cit.
4. The per capita personal income in Alabama; and
5. Time, a catch-all for those factors which cannot conveniently be measured separately but which change more or less slowly and smoothly.

Deflation of variables 2 and 4 by 3 leads to the final relationship:

$$X_1 = F(X_2, X_3, X_4)$$ (3.5.1)

where $X_1$ and $X_4$ represent per capita consumption and time respectively and

$$X_2 = \text{the real price of gasoline},$$

$$X_3 = \text{the real per capita personal income in Alabama}.$$

The estimated equation is as follows:

$$\log X_1 = -.57 - 0.06 \log X_2 + 0.90 \log X_3 + 0.25 \log X_4$$ (3.5.2)

$$\begin{align*}
(0.20) & (0.80) & (0.003)
\end{align*}$$

As can be seen from the standard errors quoted, time is the only statistically significant variable tested. Income is significant at the 30% level and price is statistically equal to zero.

On the basis of generally accepted statistical criteria, the conclusion thus emerges that per capita consumption of gasoline may be considered as a function of time only; but such a conclusion is of very limited practical importance. For the gasoline industry or the government policy makers it would be useful to have even an imperfect indication of how consumers react to changes in important economic magnitudes, so as to be able to formulate their strategies.
accordingly. Clearly, this study does not offer this opportunity, since the author did not make any further attempt to improve his results by considering alternative formulations of his gasoline demand model.

On the other hand if one accepts that "the use of a trend in correlation analysis constitutes a confession of ignorance of fundamental factors involved"*, one might conclude, perhaps with some exaggeration, that this ignorance is the only significant feature of the study.

3.6 Houthakker and Taylor (H.T.) Study**

Houthakker and Taylor in an econometric study designed for projecting all items of United States' consumer expenditure into the future, estimated the demand for gasoline and lubricating oil. They used a dynamic "state-adjustment" model***, the underlying assumption of which is that "current decisions are influenced by past behaviour".

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*** Stock adjustment for durables and habit formation for non-durables. The only difference is in the sign of the parameter relating stock and current purchases, being negative for durables and positive for non-durables.
The current values of the so-called "state variables" (e.g. physical or habit stocks) represent the effect of past behaviour. These "state variables" are in turn changed by current decisions and the net result is that of a "distributed lag". In other words, current behaviour (expressed by the expected value of the dependent variable in period t) depends on all past values of the predetermined variables.

The regression equation for gasoline and lubricating oil, selected from several estimated equations, is as follows:

$$q_t = 0.8913q_{t-1} + 0.0185x_t + 0.0046x_{t-1} - 1.4435d_t \quad (3.6.1)$$

where $q_t$ and $x_t$ represent quantity and consumer's real personal expenditure (instead of disposable income) per capita, respectively. The price variable was eliminated since its coefficient proved to be statistically insignificant. A dummy variable is used, denoted by $d_t$, to capture the apparent upward shift of the function in the post-war period. The stock of vehicles is implicit in the above equation having been eliminated by appropriate mathematical manipulations. Houthakker and Taylor's work can only be treated as an attempt to establish new theoretical foundations applicable to the demand for both durables and non-durables. This is achieved at the expense of a more detailed investigation of the commodities concerned. Prices, for example, other than own price, are not considered. Thus a direct comparison between this work and other detailed studies of gasoline seems to be inappropriate.
3.7 O'Riordan Study*

The purpose of this study is to estimate the price elasticity of demand for petrol in Ireland, where the product is one of the main sources of indirect tax revenue. O'Riordan uses a number of factors apart from the price of petrol to explain demand variations.

The use of a single or a multi equation system is the first consideration. Traditional economic theory dictates that the demand for a product should be investigated through a system of demand and supply equations where quantity and price appear as endogenous variables (determined within the system). This, according to the author, is not a realistic representation of the petrol market.

"About three quarters of the market price of petrol is excise duty and most price changes are due to changes in tax. Thus it does not seem reasonable to regard price as anything but a variable which is determined outside the system."

The endogeneity of the other variables is not discussed and thus the above argument leads to the construction of a single equation model which amounts to assuming that sellers try to maximise the quantity sold at any given price. Shifts, therefore, in the horizontal supply curve identify the demand curve. The author selects with some care the variables which are likely to cause variations in petrol demand.

They are:
Real income in the community ($Y = \text{GNP}$ at 1958 prices) whose influence is expected to be quite strong, given the substantial changes in its level.
The stock of vehicles ($C = \text{number of cars registered in August of the year in question}$), as representing the influence of variables relating to the decision to buy a car, such as vehicle prices, insurance, and other fixed costs.
As to the third variable, that is the price of petrol, two versions are tried: $P_a$ (index of actual price of petrol) and $P_r = \frac{P_a}{\text{Consumer Price Index}}$. This is because it is not obvious whether consumers are free of money illusion, particularly in the case of petrol, since

"most people believe that petrol price has risen faster than the general level of prices in the last few years, but the variable $P_r$ shows that the reverse is the case".

A relative price index of public transport ($P_t$) is included as well, to allow for the influence of substitutes.

"The final factor affecting the demand for petrol is the change from petrol to diesel as a fuel for commercial vehicles".

This variable called the "dieselisation factor" (D) plays an important role in the analysis and deserves some detailed discussion. Its construction is based on the study of the
sample observations which shows stability of the ratio of annual consumption of diesel to annual consumption of petrol at about .25 to 1 from 1962 onward.

However, some correction is necessary to the first half of the period studied (1953-1969) because this ratio was not constant. The correction is achieved as follows:

Define

\[ Q = Q_c + Q_p \tag{3.7.1} \]

where \( Q \) is total, \( Q_c \) commercial and \( Q_p \) private demand for petrol.

\( Q_d \)
as diesel used (all commercial); and

\( R \)
as a constant representing the petrol/diesel consumption substitution ratio in normal road-haulage.

Now, \( Q \) and \( Q_d \) are observable but \( Q_c \) and \( R \) are not.

Thus, O'Riordan assumes that:

Total Commercial Consumption of motor fuel

\[ = .25 \times \text{Private Consumption of motor fuel} \tag{3.7.2} \]

that is,

\[ Q_d + \frac{1}{R} Q_c = .25 Q_p \tag{3.7.3} \]

Adding \(.25 Q_c \) to both sides, (3.7.3) becomes

\[ Q_d + \frac{1}{R} Q_c + .25 Q_c = .25 Q \tag{3.7.4} \]

Solving for \( Q_c \) one obtains

\[ Q_c = \frac{1}{\frac{1}{R} + .25} (.25 Q - Q_d) = R'(.25 Q - Q_d) \tag{3.7.5} \]

Thus, \( Q_c \) becomes a function of \( R \) and the observed \( Q \) and \( Q_d \). Substituting back into (3.7.1), one obtains:
\[ Q = Q_p + R'(.25 Q - Q_d) \]

or \[ Q = Q_p + R'D \] \hspace{1cm} (3.7.6)

In this way total demand for petrol becomes a function of the variables mentioned before. However, this is achieved on the basis of a very strong and arbitrary assumption stating that total commercial consumption of motor fuel is equal to 25\% of the corresponding motor fuel consumption (equation 3.7.2).

The functional form selected for the estimation of the parameters is as follows:

\[ \log(Q-k) = \log b_0 + b_1 \log Y + b_2 \log P + b_3 \log C + b_4 \log D + b_5 \log P_t + \log u \] \hspace{1cm} (3.7.7)

The constant \( k \) is included so that the "best" estimates are obtained as a product of a trial and error process.

O'Riordan further assumes that the results are satisfactory when the dependent variable is transformed as \((Q - 60)\) in the case of \( P_a \) and \((Q - 35)\) in the case of \( P_r \).

The estimated equations are:

1. Using **actual price** \((P_a)\)

\[
(Q-60) = -4.869 + 2.5415 \log Y - 1.6913 \log P_a + 1.8308 \log C +
0.0649 \log D - 0.7011 \log P_t
\]

\[
(6.88) \hspace{1cm} (-7.57) \hspace{1cm} (9.48) \hspace{1cm} (2.11) \hspace{1cm} (-2.69)
\]

\[ R^2 = .9991 \]

2. Using **relative price** \((P_r)\)

\[
(Q-35) = -1.4086 + 1.9801 \log Y - 1.2373 \log P_r + 0.5471 \log C +
0.0376 \log D - 0.58 \log P_t
\]

\[
(9.12) \hspace{1cm} (-6.38) \hspace{1cm} (5.99) \hspace{1cm} (2.28) \hspace{1cm} (-2.96)
\]

\[ R^2 = .99914 \]
The price elasticity coefficient is where the author's interest is concentrated. Thus its magnitude makes him suggest that:

"it is quite useless to raise the rate of tax on petrol if the purpose is to gather more revenue".

O' Riordan's suggestion, which seems to be false, can be attributed to several shortcomings of the study.

The price elasticities quoted seem to be very high. Non-availability of substitute fuels (for the largest part of the vehicle population) as well as the fact that petrol expenditure is only one part of the total cost of motoring would suggest a much lower price elasticity.

The transformation of the dependent variable by using a constant, the value of which is selected after a trial and error process, seems to be quite arbitrary.

The sign of the "price of public transport" variable appears to be incorrect. On a priori economic grounds one would expect a positive sign given that private and public transport, as alternative ways of satisfying the same need, can be considered as substitutes.

Finally, one may raise some doubts about the treatment of the dieselisation factor. In the submodel constructed, R'D represents an approximation for the declining commercial demand for petrol. D is a function of Q and Q_d, but R' is an unknown constant which has to be estimated if R'D is to be included in the regression. If R' were known, R'D could be subtracted from Q and thus a regression equation...
explaining variations in private demand could be used; but
the author includes D on the right hand side of the multi-
plicative model as an explanatory variable. Moreover, as
can be seen from the data appendix, D takes the value zero
after 1962 and therefore a model such as the proposed one
cannot be used since the logarithms of D cannot be computed
for the second half of the period under consideration.

It seems, therefore, that because of these drawbacks
such a model is unlikely to be useful for policy purposes.

3.8 J. Ramsey, R. Rasche, and B. Allen (R.R.A.) Study*

In this study, the demand side of the total U.S.A.
gasoline market is considered. Nevertheless, the authors
find it necessary to specify a simultaneous demand-supply
model for identification purposes. Total demand is split
into private (Q_d) and commercial (Q_c). In the private
market, variations in the quantity demanded per household
are explained in terms of variations in real disposable
income per household (y) and changes in the proportion of
the 16-24 age group in the population (t_p). This is
based on the life-cycle consumption hypothesis. Price
of gasoline appears as an endogenous variable. Passenger
trains (rail commuter lines) were considered as the
alternative mode of transport (P_t). Commercial demand,

* J. Ramsey, R. Rasche and B. Allen: 'An Analysis of the
Private and Commercial Demand for Gasoline', The Review
of Economics and Statistics, Volume VII, November 1974,
No. 4, p.p. 502-507.
on the other hand, is explained in terms of the relative prices of diesel fuel and gasoline \( (P_d \text{ and } P_{cg} \text{ respectively}) \) and an index of the total demand for all types of carriers expressed in terms of annual ton-miles \( (f_c) \).

The overidentification of the two demand equations requires a suitable technique, and two stage least squares (2SLS) is selected as such. The equations used for estimation took the following form:

Private demand:

\[
Q_d = \tilde{\sigma}_0 \text{ Exp}\{\tilde{\sigma}_1 p_g + \tilde{\sigma}_2 p_t + \tilde{\sigma}_3 t_p + \tilde{\sigma}_4 y^{-1}\} \cdot e^{u_d}
\]

Commercial demand:

\[
Q_c = \theta_0 \text{ Exp}\{\theta_1 p_{cg} + \theta_2 p_d + \theta_3 f_c\} \cdot e^{u_c}
\]

The signs of the regression coefficients satisfy the usual a priori economic criteria, apart from the sign of \( \tilde{\sigma}_3 \) which is not specified. As for the calculated elasticities, they are as follows:

**Private demand:**

The (mean) gasoline price elasticity is equal to \(-.77\).

The (mean) train travel price elasticity is equal to \(.39\).

The (mean) age group elasticity is equal to \(-.54\); and

The (mean) income elasticity is equal to \(1.34\).

**Commercial demand:**

The (mean) gasoline price elasticity is equal to \(-3.8\).

The (mean) diesel fuel price elasticity is equal to \(3.4\).

The (mean) \( f_c \) elasticity is equal to \(0.89\).
A number of comments can be made with reference to the RRA study. First, the static nature of the model implies that equilibrium is achieved within one year. The adequacy of a static model to represent the decision-making process in markets such as gasoline is questionable: it seems preferable to use dynamic models when dealing with markets where the product under consideration is technologically related to other equipment. The absence of any attempt in this direction is one of the important shortcomings of the study. Secondly, the restrictive form of the function employed implies that the relevant elasticities are functions of the corresponding variables only. In fact the elasticities are given by terms of the form $\partial p$ for price and $-\chi y^{-1}$ for income*.

* The derivation of elasticities may be illustrated by the following example:
Consider the exponential function
\[ Q = A \exp(rt) \]
or \[ Q = A \cdot e^{rt} \]
where $A$ and $r$ are constants.
Differentiation of the function with respect to $t$ will yield
\[ \frac{dQ}{dt} = A \cdot r \cdot e^{rt} \]
and therefore the corresponding elasticity ($n_t$) will be:
\[ n_t = \frac{dQ}{dt} \cdot \frac{t}{Q} \]
\[ = A \cdot r \cdot e^{rt} \cdot \frac{t}{A \cdot e^{rt}} \]
\[ = rt \]
which/
The model constantly underpredicts* gasoline consumption when it is used for the years 1970 to 1972, probably because of the form of the function. Thirdly, an explanation for not specifying the sign of the coefficient $\delta_3$ is not provided. The inclusion in the relevant equation of a variable representing the proportion of the 16-24 age group in the population is based on the Ando-Modigliani life-cycle consumption hypothesis, according to which:

"the typical individual has an income stream which is relatively low at the beginning and end of his life, when his productivity is low, and high during the middle of his life... on the other hand, the individual might be expected to maintain a more or less constant or perhaps slightly increasing level of consumption throughout his life. The constraint on this consumption stream is that the present

which states that for this form of functional relationships the point elasticity with respect to a certain variable is equal to the product of the value of the variable at that point times the coefficient corresponding to that variable. See: A.C. Chiang: 'Fundamental Methods of Mathematical Economics', McGraw-Hill Kogakucha Ltd., Tokyo, 1967, chapter 10, p.p. 266-306.

* The size of underprediction is not given.
value of his total consumption does not exceed the present value of his total income. This model suggests that in the early years of a person's life, he is a net borrower. In the middle years, he saves to repay debt and provide for retirement. In the late years he dissaves**.

According to the above interpretation, younger age would be associated with lower absolute consumption and therefore a negative relationship between age and consumption would be justifiable. However, if it is accepted that younger people tend to have a higher propensity to consume, in the aggregate a population with a younger average age would tend to spend proportionately more on motor gasoline, in which case a positive relationship between age and consumption would be equally acceptable. Such a conclusion though is more confusing than illuminating. Inclusion of a variable whose qualitative effect is uncertain is of very little analytical value, and it seems as an attempt to increase the explanatory power of a model using variables whose directional effect cannot be easily verified. Although investigation of the influence of age on consumption would be of interest, it seems that a cross-section rather than time-series analysis could provide a more appropriate framework.

3.9 Houthakker, Verleger and Sheehan (H.V.S.) Study*

This study employs an assumption underlying the flow-adjustment model of demand. Accordingly, the stock of energy consuming equipment is assumed to be fixed in the short-run and the rate of its utilisation is taken as a function of 'normal economic influences'**. Such a specification, they argue, corrects for the inadequacy of data referring to changes in the characteristics of the capital stock involved. At the same time, the importance of elements such as 'habit formation' in investigating the demand for 'narrowly specified consumption goods' is explicitly taken into consideration by the inclusion in the set of explanatory factors of a lagged dependent variable.

The desired demand for gasoline in state i during time period t, q_{it}^{d}, is assumed to be a function of income, \( y_{it} \), and price, \( p_{it} \), that is:

\[
q_{it}^{d} = f(p_{it}, y_{it}) \tag{3.9.1}
\]

or explicitly \( q_{it}^{d} = a_{it}^{p} y_{it}^{b} \tag{3.9.2} \)

A simple adjustment process is assumed, of the form

\[
q_{it}/q_{i,t-1} = (q_{it}^{d}/q_{i,t-1})^{\theta} \tag{3.9.3}
\]

where \( 0 < \theta < 1 \)

---


** Ibid, p. 413.
This hypothesis states that at any given point in time any discrepancy between actual ($q_{it}$) and desired ($q_{it}^d$) consumption of gasoline is not made up instantaneously. It is assumed instead that the adjustment of $q_{it}$ to $q_{it}^d$ is spread over time and only a fraction $\theta$ is made up during each period. Substituting (3.9.2) into (3.9.3) and taking logarithms, one derives the following equation:

$$\ln q_{it} = \theta \ln a + \theta \gamma \ln p_{it} + \theta \beta \ln y_{it} + (1-\theta) \ln q_{it-1} \quad (3.9.4)$$

This relationship is estimated by the error (or variance) component technique first developed by Balestra and Nerlove* which is appropriate for models containing a lagged dependent variable, since use of OLS would produce biased estimates**.

The model was fitted to quarterly data on gasoline consumption for the interval 1963-1972 for 48 states and the district of Columbia (number of observations $N = 1960$). The results show a short-run price elasticity equal to -.075, an income elasticity equal to .303 and a lagged consumption


coefficient of .696 ($R^2 = .92$). The lagged consumption coefficient implies a value of $\Theta$ equal to .304 which means that only 30% of any discrepancy between actual and desired demand is made up in the first period. This, in turn, implies a slow adjustment and apparently establishes the importance of this kind of lag in the equation. The long-run elasticities are -.24 for price and .98 for income*. A comparison with the elasticities derived by using simple OLS (-.081 for price, .341 for income and a lagged consumption coefficient of .6595 with $R^2 = .979$), with a different intercept for each state - allowing for climatic differences, urbanization, etc. - shows that the superiority of the errors component technique argument is not very obvious; while the results about elasticities are virtually identical, the explanatory power of the model with state intercepts is higher as may be seen from the values of the coefficient of determination ($R^2$). As HVS point out 'this observation may be regarded as reassuring in view of the robustness of least-squares estimators'**.

Although the HVS model is interesting, one may question its practical importance. This is because a formulation based on the assumption of flow adjustment is consistent

* The relationship between long-run (LR) and short-run elasticities (SR) is given by:

$$LR = SR \div \Theta$$

where $\Theta$ is the adjustment coefficient.

** Houthakker et. al., op. cit., p. 416.
with two totally different interpretations, giving rise to an identification problem: while the estimating equation derived above implies that gasoline demand is influenced by price and income it is also consistent with the hypothesis that existing demand is influenced neither by prices nor income. If the quantity demanded of petrol per capita \( q_{it} \) is taken as the product of average miles per gallon \( g_{it} \) and the per capita stock of cars \( s_{it} \), and the latter is assumed to depreciate by a fraction \( \delta \) during every period, one has:

\[
q_{it} = g_{it} \cdot s_{it} \quad (3.9.5)
\]

and

\[
s_{it} = (1-\delta)s_{i,t-1} + r_{it} \quad (3.9.6)
\]

(where \( r_{it} \) stands for new car registrations per capita).

By substituting (3.9.6) into (3.9.5), one obtains:

\[
q_{it} = g_{it} s_{i,t-1} (1-\delta) + q_{it} r_{it} \quad (3.9.7)
\]

Now assuming that \( g_{it} \) remains constant over time, (3.9.7) may be written as:

\[
q_{it} = q_{it}^R + (1-\delta)q_{i,t-1} \quad (3.9.8)
\]

where \( q_{it}^R \) is the incremental demand arising from new registrations. If \( q_{it}^R \) is made a function of income and price, then (3.9.8) simplifies to:

\[
q_{it} = a + \beta y_{it} + \gamma p_{it} + (1-\delta)q_{i,t-1} \quad (3.9.9)
\]

which is consistent with the hypothesis that price influences petrol demand only through the purchase of new cars.

The fact that two quite different hypotheses give rise
to the same statistical equation obviously has undesirable implications. This is because while the first hypothesis suggests that - provided there is a response to price changes - a higher price per gallon of petrol will result in a reduction of demand to a preset level, the second hypothesis implies that this is possible only to the extent that high prices will lead consumers towards buying smaller cars.

3.10 Dewees, Hyndman and Waverman (D.H.W.) Study *

In this study the authors recognise the need for a sophisticated model, but pragmatic reasons such as results wanted for policy conclusions in a short period and data limitations apparently force them to consider a single-equation model. They select the variables which are likely to affect gasoline consumption, and they formulate their basic equation as:

$$G = f(p, y, URB, PA) \quad (3.10.1)$$

where

- $G$ = sales of gasoline per capita;
- $p$ = real price of gasoline;
- $y$ = real personal disposable income per capita;
- $URB$ = degree of urbanisation;
- $PA$ = real price index of automobiles.

The model was applied to a cross-section of Canadian provincial time series data, and five mathematical forms were tried. First, the static equation:

\[ \log G_t = a + b \log P_t + c \log Y_t + d \log URB_t + e \log PA_t \]  

(3.10.2)

which assumes that equilibrium is achieved within one year. Secondly, the same form as above but with a four year distributed lag on price and income, with weights 0.15 for year one, 0.25 for year two and 0.3 for years three and four. These weights are imposed on the variables in a somewhat arbitrary way which the authors justify as "our understanding of the rate of utilization of automobiles and the composition of the fleet in terms of used and new cars"*. Thirdly, a dynamic form is tried with the same explanatory variables appearing as in the static equation. The difference here is that the dependent variable is formulated as \( GF \), that is free demand for gasoline. This is defined as the quantity sold in period \( t \) less 80% of the quantity sold in period \( t-1 \). "This formulation assumes that because of retirement from the fleet and decreased use with increasing age, current gasoline consumption by those cars remaining from the previous year's fleet will be only 80% of the previous year's consumption. The remaining current demand is attributed to new cars"**.

Clearly, such a formulation is unrealistic, because it does not take into consideration the fact that the


number of retiring units varies considerably over time, and that the characteristics of those units with respect to fuel economy may be quite important. Therefore, a constant percentage of consumption cannot be attributed to them. On the other hand, increasing age might imply greater consumption per mile and thus the net result cannot be specified a priori. The fourth regression equation has the form:

$$\log G_t = a + b \log P_t + c \log Y_t + d \log G_{t-1}$$

(3.10.3)

whose characteristics have been mentioned before (HWS study).

The last equation:

$$\log G_t = a + bP + c \frac{1}{Y} + dURB_t + ePA_t$$

(3.10.4)

implies that each elasticity is a function of the relevant variable only, as was pointed out previously (RRA study).

The results derived using the static equation show a statistically significant income elasticity of about .82 (both for Canada and the individual provinces) and price elasticities of the individual provinces that range from -.4 to -.56. The distributed lag model, and the dynamic model, give coefficients with the right sign but demand seems to be more price inelastic, particularly in the case of the distributed lag model, ranging from -0.17 to -.037. It is interesting to note that the elasticities referring to income, degree of urbanization and price index of cars are almost identical whether they refer to Canada or to individual provinces, for most of the forms.
tried. Moreover, the price elasticity for Canada is almost equal to the simple arithmetic mean of the individual price elasticities. Apart from the criticism relating to the arbitrary way in which the authors specified their models, one can criticise the study on statistical grounds as well. Although "examination of the residuals shows a high degree of autocorrelation among residuals within each province" no attempt is made to correct for autocorrelation.

The practical usefulness of the study and the results presented therefore seem to be very limited, particularly if the model is to be used for policy recommendations.

3.11 Conclusion

In this chapter a number of studies on the demand for petrol were reviewed. A study based on an engineering approach was followed by a detailed summary of econometric work presented in chronological order. The detailed and one study at a time presentation reflects the belief that quantitative estimates cannot be easily compared without explicit reference to the way a model has been built. Different formulations generate different elasticity estimates and if one were to draw a broad conclusion this would be that the short-run price and income elasticities of petrol demand appear to be smaller (in absolute values) than their long-run counterparts. Synopsis in a chronological order is of interest in that it helps one identify the path of development in the field of petrol demand. From

this point of view an attempt towards dynamising the relevant demand equations is evident.

Although model objectives differ and it seems that no methodology has yet been demonstrated to be best for all purposes, the general line of thought one should follow may be summarised as follows:

A successful formulation of a petrol demand model should recognise at the outset the need to distinguish between demand in the short-run and demand in the long run. The rationale behind this is that petrol does not provide satisfaction directly but it is desired as an input into other activities that do provide utility, and which use a capital stock of considerable durability. Since durable goods are involved, the distinction between short-run and long-run should be made with reference to that stock and not necessarily to specific lengths of time. Under such an interpretation the short-run should refer to a situation where the influence of the stock of equipment has been taken care of and only its rate of utilisation varies; the long-run demand should refer to demand variations due to both variations in the stock of equipment and its average rate of utilisation. However, observing a time series of petrol consumption, one cannot really accept that its variation is solely due to variations in the rate of utilisation of the underlying (and assumed constant) consuming equipment. Hence 'econometric estimation of the model requires explicit estimates of the stock of consuming capital goods', or elimination of its influence through

appropriate mathematical formulation. The first method has been followed by O'Riordan but his conclusions seem to be of limited usefulness because of the shortcomings pointed out in the relevant section (3.7.). The second method, as employed for the derivation of short-run elasticities in markets such as electricity (Fisher and Kaysen) and natural gas (Balestra) is not found in petrol demand studies, and a probable explanation could be the incorporation in these models of the rather strong assumption that the stock of consuming appliances grows at a constant rate over time. However, the various formulations employed instead, do not seem to provide a satisfactory substitute. The 'flow-adjustment' model, although it provides a dynamic formulation which is a desirable feature for a petrol demand model to possess, it raises a question of identification which is undesirable from a policy point of view (section 3.9). The disadvantages of using time as one of the explanatory factors is probably best expressed in the criticism of Broome's work (section 3.5). The formulation of models through the introduction of variables whose qualitative effect cannot be specified a priori (section 3.8) or may be questioned (section 3.10) are rather considered as statistical associations and not as an attempt to analyse fundamental factors involved.

A satisfactory model should be flexible enough to allow investigation of the influence of economic factors other than the product's own price and income; the models
reviewed hardly satisfy such a requirement.

Finally, the technological complementarity characterising vehicle ownership and use and petrol demand should be taken into account explicitly.

Because of the reasons provided above, it seems that the models summarised in this chapter are of limited value and practical usefulness. In the next chapter, the questioning of the validity of the ceteris paribus assumption in the case of energy products leads to the formulation of models based on stock effect considerations. These are a preparatory step towards the final model proposed in chapter 5.
4.1 Introduction

In chapter 2 the conclusion was reached that the sources of poor results should be looked for in the "ceteris paribus" assumption underlying the models tested.

Henry L. Moore in his "Economic Cycles: Their Law and Cause" states:

"The "other things" that are supposed to remain equal are seldom mentioned and are never completely enumerated; and consequently the assumption that, other unmentioned and unenumerated factors remaining constant, the law of demand will be of a certain type, is really tantamount to saying that under conditions which are unanalyzed and unknown, the law of demand will take the supposed definite form".*

The "ceteris paribus" assumption is a crucial one, and its significance becomes of paramount importance when one deals with products that due to their nature are related to stocks of consuming equipment. Petrol is a characteristic example of a technological relationship or technological complementarity, which dictates that one product

(petrol) is necessary if another product or service (private motoring) is to be enjoyed. Hence, consideration of a "stock effect" is clearly indicated and our attention is turned in this direction.

4.2 Stock effect considerations

The idea of allowing for a "stock effect" in a demand equation, which takes the analysis to what was called a pragmatic approach to demand problems is not new. In empirical investigations it has been used several times and an example is a study by Balestra.*

Investigating the residential and commercial demand for natural gas in the United States, Balestra defines the quantity of natural gas consumed during a period $t$, $(G_t)$, as the product of the stock of gas consuming appliances, $(S_t)$, and what he calls "the rate of their utilisation" during the period $(\lambda_t)$, which is assumed to be a function of the real price of gas and real income per capita.

* P. Balestra, op. cit., p. 20 onwards.

This particular study has been chosen for two reasons. First, Balestra is one of the first authors who considered a stock of appliances effect in a demand equation. Second his study constitutes an excellent starting point for the improvements proposed later.
\[ G_t = S_t \cdot \lambda_t \quad (4.2.1) \]

However, a rather important element is missing from the above equation, and, as we hope to show, consideration of it would lead to an improvement of the analysis of demand for energy products in general and of the demand for petrol in particular. The argument may be established in two different ways

i) By definition

\[ \lambda_t = \frac{G_t}{S_t} \quad (4.2.2) \]

Multiplying and dividing the right hand side of \( (4.2.2) \) by \( (TH) \), that is total hours of use during \( t \), we obtain:

\[ \lambda_t = \left( \frac{TH}{S} \right)_t \cdot \left( \frac{G}{TH} \right)_t \quad (4.2.3) \]

The first factor on the right hand side of \( (4.2.3) \), being the ratio of total hours of use to the total number of appliances is the average period of use per appliance during \( t \), \( \bar{h}_t \). This may be considered, for reasons that will be explained later, as the "true rate of utilisation".

The second factor, is the ratio of total units consumed to the total period of use of all appliances and therefore represents the average consumption characteristics of the average appliance (gas consumption per hour of use, or \( \bar{c}_t \)).

Thus \( \lambda_t \) may be redefined as

\[ \lambda_t = \bar{h}_t \cdot \bar{c}_t \quad (4.2.4) \]
and consequently

$$\tau_t = \bar{h}_t \cdot \bar{c}_t \cdot S_t$$ \hspace{1cm} (4.2.5)

Now, the average period of use $\bar{h}_t$ is the rate of utilisation and it is reasonable to assume that it may be considered, as a first approximation, as a function of real income per capita and price prevailing in period $t$. But the consumption characteristics of the average appliance, $(\bar{c}_t)$, are associated with the period of time during which the consumer made his decision to buy a specific appliance. Once the decision is taken about the purchase of an appliance with certain consumption characteristics, what may be changed, at least in the short-run, is the true rate of utilisation $\bar{h}_t$. Consider for example a consumer who owns one unit of gas consuming equipment, whose consumption characteristics are $X$ units per hour of use. In the short-run, if the consumer feels that either his income decreases or that the real price per unit of gas increases he might decide to decrease the period of use of the appliance from say $k$ hours per period to $k_1$ hours, with $k_1 < k$. However, in the short-run he cannot change the average consumption characteristics of the specific appliance given that in the short-run both the amount of equipment held and the consumption characteristics of it by assumption are supposed to remain constant. Regardless of the period of use, a specific appliance will consume a certain amount of
units per hour of use (X units per hour in our example).*

In the long-run, however, the consumer is free not only to change the true rate of utilisation of the appliance(s) but the stock of appliances he holds and/or the consumption characteristics of them per period of use, the latter being conditioned by the state of technology. An increase or decrease in the number of equipment units held is conceptually straightforward. A movement towards appliances with more "economical" characteristics simply means that in the long-run the consumer might decide, considering the prevailing prices and his income, to replace an appliance consuming X units per hour of use by another that consumes X₁ units (where X₁<X), if the existing technology permits him to do so.

ii) The alternative way of establishing the superiority of definition (4.2.5) is probably simpler. Consider again Balestra's definition (4.2.1). The stock of appliances variable Sₜ, if interpreted as the number of existing natural units, suffers from the unnecessarily restrictive assumption that all stock units are considered homogeneous with respect to consumption characteristics. This, obviously, is an oversimplifying assumption that is very rarely justified in the case of most energy pro-

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* There might actually be some small variation in X because the efficiency of some (heating) appliances falls (X rises) if they are used relatively little.
ducts, and particularly in the case of petrol.

To express the existing stock of vehicles in terms of units in use would be equivalent, in the extreme case, to assuming that the proportion of large and small cars must be in a constant mix over time.

If however one argues that $S_t$ is expressed in terms of equivalent consuming units, thus achieving the desirable homogeneity condition with respect to $S_t$, $\lambda_t$ cannot be considered any more as a function of the real price of gas and income, but of the average consumption characteristics of the appliances as the derived equation (4.2.4) shows. The above examples and considerations, it is hoped, prove the superiority of definition (4.2.5).

Of course, one might argue that Balestra's simplification is inevitable given that data on the consumption characteristics of the appliances or relevant information that could be used in order to approximate them are probably not available. This is a valid argument. However, it does not limit the responsibility of the investigator who has to point out that his omission might greatly affect the estimates he reports. This point, which is of considerable importance given that the author suggests the use of his model in markets with similar technological characteristics (that is, markets for energy products) is not raised in Balestra's study. However, the previous analysis suggests that availability and utilisation of this kind of information may only strengthen the reliability of the empirical estimates, something which is of
paramount importance from a policy point of view. If for example the authorities think that variations in the quantity demanded of petrol are solely due to variations in the stock of vehicles and their rate of utilisation and no attention is paid to possible changes in the desired consumption characteristics of the stock of cars in use, imposition of a higher tax per gallon of petrol for conservation purposes, in the short-run might not affect the average normal utilisation (mileage) if this is insensitive to petrol price changes, while it may have a depressing influence, in the long-run, on the desired consumption characteristics (movement towards cars giving more miles per gallon). But if the home car industry is not flexible enough to meet the changing desires of consumers and is not given the opportunity, timewise, to adjust accordingly, the probable repercussions on the industry and even the economy as a whole might be rather serious.* The recent increasing share of the "small" car in the market, as well as the emphasis given to the consumption features of cars in almost all advertisements

* The motor industry is extremely important to the national economy, since it accounts directly for some 8% of the national output and some 13% of visible exports. See: "Society of Motor Manufacturers and Traders Ltd: "Energy Policy and the Motor Industry", October 1974."
is probably the best indication of the recent structural changes. It seems then that a succesful model of demand for petrol should be able to detect these changes.

After the clarification concerning the concept of the true rate of utilisation and the importance of the consumption characteristics it may be stated that by definition:

The actual quantity of petrol \( q_t \) consumed by any petrol-powered motor vehicle (hereafter referred to simply as motor vehicle) during a certain period \( t \), by definition is equal to the distance travelled in miles \( m_t \) times the average quantity of petrol consumed per mile (that is, the average consumption characteristics) \( c_t' \).

\[
q_t = m_t \cdot c_t' \quad (4.2.6)
\]

Accordingly, for any group of motor vehicles

\[
Q_{it} = \bar{m}_{it} \cdot \bar{c}_{it} \cdot S_{it} \quad (4.2.7)
\]

where

\( Q_{it} \) is the total quantity of petrol consumed by all motor vehicles in group \( i \), during \( t \).

\( \bar{m}_{it} \) is the average true rate of utilisation (mileage) per vehicle in group \( i \), during \( t \).

\( \bar{c}_{it} \) is the average consumption characteristics (in gallons per mile) of the "average" vehicle in group \( i \), during \( t \);

and \( S_{it} \) is the total stock of motor vehicles in group \( i \), during \( t \).
The total annual consumption of petrol in the United Kingdom is just the sum of quantities consumed by different categories of motor vehicles, and may be defined as (see table 13):

\[ Q_{1t} = Q_{1t} + Q_{2t} + Q_{3t} + Q_{4t} + Q_{5t} + Q_{6t} \]  

(4.2.8)

where

- \( Q_{1t} \) = Total annual consumption of petrol.
- \( Q_{1t} \) = Consumption by private cars and vans and motor cycles.
- \( Q_{2t} \) = Consumption by Public service vehicles and taxis
- \( Q_{3t} \) = " " (petrol powered) Goods vehicles
- \( Q_{4t} \) = " " Services and other Government
- \( Q_{5t} \) = Petroleum Industry's own consumption
- \( Q_{6t} \) = Miscellaneous.*

For our purposes it seems reasonable to consider total consumption as comprising two parts, corresponding to the most predominant categories, namely consumption by private cars (\( Q_{pt} \)) and consumption by petrol powered commercial (goods) vehicles (\( Q_{ct} \)). This simplifying assumption is justified upon consideration of table 14 which has been derived from table 13 and shows that the

* Not falling in any of the previous categories.
**TABLE 13**

U.K. End - use Consumption of petrol (in thousand tons)

<table>
<thead>
<tr>
<th>Year</th>
<th>Vehicle class*</th>
<th>(I)</th>
<th>(II)</th>
<th>(III)</th>
<th>(IV)</th>
<th>(V)</th>
<th>(VI)</th>
<th>Total</th>
</tr>
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<td></td>
<td>3030</td>
<td>195</td>
<td>2648</td>
<td>305</td>
<td>27</td>
<td>35</td>
<td>6240</td>
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<td></td>
<td>3140</td>
<td>170</td>
<td>2635</td>
<td>325</td>
<td>27</td>
<td>27</td>
<td>6324</td>
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<td>2480</td>
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<td>41</td>
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</tr>
<tr>
<td>1966</td>
<td></td>
<td>8620</td>
<td>80</td>
<td>2390</td>
<td>180</td>
<td>3</td>
<td>49</td>
<td>11322</td>
</tr>
<tr>
<td>1967</td>
<td></td>
<td>9360</td>
<td>80</td>
<td>2415</td>
<td>175</td>
<td>2</td>
<td>52</td>
<td>12084</td>
</tr>
<tr>
<td>1968</td>
<td></td>
<td>10070</td>
<td>80</td>
<td>2431</td>
<td>170</td>
<td>2</td>
<td>55</td>
<td>12808</td>
</tr>
<tr>
<td>1969</td>
<td></td>
<td>10460</td>
<td>80</td>
<td>2461</td>
<td>170</td>
<td>-</td>
<td>60</td>
<td>13231</td>
</tr>
<tr>
<td>1970</td>
<td></td>
<td>11250</td>
<td>75</td>
<td>2454</td>
<td>173</td>
<td>-</td>
<td>58</td>
<td>14010</td>
</tr>
<tr>
<td>1971</td>
<td></td>
<td>11940</td>
<td>75</td>
<td>2480</td>
<td>175</td>
<td>-</td>
<td>57</td>
<td>14727</td>
</tr>
<tr>
<td>1972</td>
<td></td>
<td>12820</td>
<td>75</td>
<td>2520</td>
<td>170</td>
<td>-</td>
<td>55</td>
<td>15648</td>
</tr>
<tr>
<td>1973</td>
<td></td>
<td>13755</td>
<td>75</td>
<td>2600</td>
<td>175</td>
<td>-</td>
<td>54</td>
<td>16659</td>
</tr>
</tbody>
</table>

* I : Private cars and vans and Motor cycles  
II: Public service vehicles and taxis  
III: Goods Vehicles  
IV: Services and other Government  
V : Petroleum industry own use  
VI: Miscellaneous

two categories account for around 98 per cent of total petrol consumption.

<table>
<thead>
<tr>
<th>Year</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1955</td>
<td>90.99</td>
</tr>
<tr>
<td>1960</td>
<td>95.46</td>
</tr>
<tr>
<td>1965</td>
<td>96.97</td>
</tr>
<tr>
<td>1969</td>
<td>97.66</td>
</tr>
<tr>
<td>1970</td>
<td>97.82</td>
</tr>
<tr>
<td>1971</td>
<td>97.92</td>
</tr>
<tr>
<td>1972</td>
<td>98.03</td>
</tr>
<tr>
<td>1973</td>
<td>98.18</td>
</tr>
</tbody>
</table>

* Derived from table 16.
On the basis of what has been previously said it may be stated that:

\[ N_{It} = N_{pt} + N_{ct} \] \hspace{1cm} (4.2.9)

Accordingly, the relevant stocks of private cars \( S_{pt} \) and goods vehicles \( S_{ct} \) are taken as corresponding to \( Q_{pt} \) and \( Q_{ct} \) respectively. Substituting (4.2.8) into (4.2.9) and assigning appropriate subscripts to the variables one obtains:

\[ Q_{It} = m_{pt} \cdot c_{pt} \cdot S_{pt} + m_{ct} \cdot c_{ct} \cdot S_{ct} \] \hspace{1cm} (4.2.10)

Equation (4.2.10) may be considered as the starting point of the formulation of different hypotheses to be tested. Most of the terms in (4.2.10), however, are not directly observable. The problem, therefore, is to link non measurable back to measured variables by making additional assumptions. As Branson has put it:

"Choosing the right assumptions and making the right linkage is the crucial art in empirical economics".*

What follows is just a modest attempt towards the practice of this art.

Let us consider in turn the factors appearing in (4.2.10). The rates of utilisation of vehicles \( m_{pt} \) and \( m_{ct} \) may be assumed to be functions of the real price of

petrol \( (PG_t) \) and real income per capita \( (YPK_t) \).*

It is reasonable to think of the variables \( \bar{c}_{pt} \) and \( \bar{c}_{ct} \) as being dependent upon a large number of factors such as the age of the car, traffic and road conditions, technology, engine capacity and so on. Unfortunately most of these factors cannot be considered since relevant information does not exist. However, information does exist referring to the engine capacity distribution of private cars and vans. This variable may be used as partly explaining the average consumption characteristics of the population of this category of cars during period \( t \). The above approximation is not altogether naïve. Intuitively it seems reasonable to assume that as the engine capacity of a car increases the amount of miles given per gallon decreases. Nevertheless, apart from common sense the previous assumption has to be based on facts and this is done in the next section.

As for the stock figures, the number of private cars and vans in use as well as the number of goods vehicles that are less than \( 1\frac{1}{2} \) tons of unladen weight are taken as approximations of \( S_{pt} \) and \( S_{ct} \) respectively. Of course

* The official annual mileage per vehicle estimates refer to private cars and the whole population of goods vehicles including diesel powered goods vehicles. That is why this approximation is made. Later, the mileage estimates relating to private cars are explicitly introduced in the analysis.
these two variables do not cover the whole population of petrol driven vehicles. Nevertheless it is believed that they do constitute a reasonable approximation. Pragmatic and other reasons as well as existing evidence may be advanced in support of this thesis. First, it is important to realise that in order to explain variations in the quantity demanded of petrol, consideration of the most crucial factors is sufficient. Regarding the number of variables to be included in the analysis Schultz for example suggests that

"Although in theory it is necessary to deal with the demand function in all its complexity in order to show that the price problem is soluble, in practice only a small advantage is gained by considering more than the first few highly associated variables."*

Second, an assumption relating to \( S_{ct} \) had to be made since information on the stock of petrol-powered goods vehicles is considered as confidential.** However, approximating \( S_{ct} \) by the number of goods vehicles less than 1½ tons of unladen weight is likely to be reasonable upon consideration of the following two tables (15 and 16). From these two tables it can be seen that through-

* Schultz (quoted in Broome, op. cit., p. 80).
** Communication with the Statistics Department of the Society of Motor Manufacturers and Traders.
out the period 1964-1973 the number of new registrations of petrol driven goods vehicles almost exactly coincides with the number of new registrations of goods vehicles less than 1 1/2 tons of unladen weight. This constitutes a reason to believe that the assumption made is justified. Hence, after providing evidence, in the following section concerning the assumption made about the consumption characteristics of private vehicles we proceed to the formulation of the first hypothesis to be tested.

4.3. The relationship between consumption characteristics and engine capacity of cars.

In order to test the assumption referring to the relationship between consumption characteristics (expressed in miles per gallon) and engine capacity of cars, information relating to these two factors was obtained from one of the existing car magazines.*

The amount of miles given per gallon of petrol** by a car with specific features was taken as a function of its engine capacity and a simple two-variable regression was performed. Note that in such a relationship the requirements of single equation regression analysis as a statistical technique are satisfied. This is because

* Motor Guide, April 1974. Data used are given in Appendix.
** Based on manufacturers tests.
<table>
<thead>
<tr>
<th>Year</th>
<th>not over 12 cwt</th>
<th>12-16 cwt</th>
<th>16-1 ton</th>
<th>1 ton-1½ tons</th>
<th>1½ tons or less</th>
<th>All vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1964</td>
<td>0,737</td>
<td>55,616</td>
<td>31,658</td>
<td>50,138</td>
<td>146,149</td>
<td>224,817</td>
</tr>
<tr>
<td>1965</td>
<td>11,966</td>
<td>51,970</td>
<td>28,083</td>
<td>51,363</td>
<td>144,142</td>
<td>221,488</td>
</tr>
<tr>
<td>1966</td>
<td>12,159</td>
<td>50,610</td>
<td>22,797</td>
<td>52,476</td>
<td>138,042</td>
<td>220,211</td>
</tr>
<tr>
<td>1967</td>
<td>13,569</td>
<td>51,397</td>
<td>25,579</td>
<td>47,374</td>
<td>137,919</td>
<td>214,723</td>
</tr>
<tr>
<td>1968</td>
<td>8,667</td>
<td>58,387</td>
<td>21,686</td>
<td>54,845</td>
<td>143,585</td>
<td>224,965</td>
</tr>
<tr>
<td>1969</td>
<td>6,012</td>
<td>62,399</td>
<td>19,168</td>
<td>58,213</td>
<td>145,792</td>
<td>234,308</td>
</tr>
<tr>
<td>1970</td>
<td>5,487</td>
<td>64,542</td>
<td>16,540</td>
<td>64,273</td>
<td>150,842</td>
<td>231,765</td>
</tr>
<tr>
<td>1971</td>
<td>6,108</td>
<td>64,459</td>
<td>21,090</td>
<td>68,803</td>
<td>160,460</td>
<td>230,161</td>
</tr>
<tr>
<td>1972</td>
<td>7,151</td>
<td>72,576</td>
<td>30,286</td>
<td>81,945</td>
<td>191,958</td>
<td>261,965</td>
</tr>
<tr>
<td>1973</td>
<td>7,152</td>
<td>72,778</td>
<td>39,910</td>
<td>85,856</td>
<td>205,696</td>
<td>283,505</td>
</tr>
</tbody>
</table>

TABLE 16

New Registrations of General Goods Vehicles (Great Britain),
by type of fuel (thousand)

<table>
<thead>
<tr>
<th>Year</th>
<th>Electric (1)</th>
<th>Petrol (2)</th>
<th>Diesel (3)</th>
<th>All Vehicles (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1964</td>
<td>2.1</td>
<td>145.9</td>
<td>77.1</td>
<td>225.1</td>
</tr>
<tr>
<td>1965</td>
<td>2.2</td>
<td>143.9</td>
<td>75.5</td>
<td>221.6</td>
</tr>
<tr>
<td>1966</td>
<td>1.9</td>
<td>137.7</td>
<td>80.5</td>
<td>220.2</td>
</tr>
<tr>
<td>1967</td>
<td>1.4</td>
<td>138.1</td>
<td>75.2</td>
<td>214.7</td>
</tr>
<tr>
<td>1968</td>
<td>1.7</td>
<td>141.6</td>
<td>81.6</td>
<td>224.9</td>
</tr>
<tr>
<td>1969</td>
<td>1.0</td>
<td>142.6</td>
<td>90.0</td>
<td>234.3</td>
</tr>
<tr>
<td>1970</td>
<td>1.4</td>
<td>145.9</td>
<td>84.5</td>
<td>231.8</td>
</tr>
<tr>
<td>1971</td>
<td>1.6</td>
<td>153.5</td>
<td>75.1</td>
<td>230.2</td>
</tr>
<tr>
<td>1972</td>
<td>1.5</td>
<td>185.1</td>
<td>75.4</td>
<td>262.0</td>
</tr>
<tr>
<td>1973</td>
<td>1.4</td>
<td>199.9</td>
<td>82.2</td>
<td>283.5</td>
</tr>
</tbody>
</table>

there is a clear one-way relationship between the explanatory variable $EC_i$ (engine capacity of car $i$) and the dependent variable $Z_i$ (miles given per gallon of petrol by car $i$). Furthermore, there are no errors involved in the measurement of the exogenous variable since this is an engineering concept that can be precisely measured.

The results obtained are presented in table 17. A look at this table suggests two important conclusions:

i) that the assumption of taking engine capacity as a proxy for part of the average consumption characteristics of a car is justified* and

ii) that engine capacity explains a considerable proportion of the variation on the dependent variable (61%) as indicated by the value of $R^2$, but not all the variation. This result was expected since the relevant factors omitted for lack of information (such as car weight) play an equally crucial role in the determination of miles given by a car per gallon of petrol.

* Note that the negative coefficient obtained implies a negative relationship between engine capacity and miles per gallon of petrol or, alternatively a positive relationship between engine capacity and gallons per mile.
TABLE 17

Regression estimates showing the relationship between miles/gallon of petrol ($Z_i$) and engine capacity of cars ($EC_i$) (Primes denote logarithms)

$$(Z_i)' = a_1(EC_i)' + u_i'$$

(Variables in deviation from their means)

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Estimate</th>
<th>t-value</th>
<th>$R^2$</th>
<th>D-W statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_1$</td>
<td>-0.509</td>
<td>9.832</td>
<td>0.605</td>
<td>2.32</td>
</tr>
</tbody>
</table>
4.4 Formulation of hypotheses

On the basis of what has been previously said, the first hypothesis to be tested is as follows:

Hypothesis A

"Variations in the total quantity consumed of petrol per year (Qt) may be explained in terms of variations in the average real price of petrol (Pt),* real disposable income per capita (YPKt), the stock of private cars and vans in use (Sp), the stock of petrol driven commercial goods vehicles (Sc), and an error term (et) representing the net influence of all other factors not accounted for by the model."

In functional form hypothesis A may be expressed as:

\[ Q_{t} = f(P_{t}, YPK_{t}, EC_{t}, SP_{t}, SC_{t}, e_{t}) \]

Note that not all factors appearing in the above relationship are truly exogenous, as a single equation model would require. The variables representing the relevant stock (Sp and Sc) as well as engine capacity of private cars (Ec) are themselves the outcomes of economic decisions taken with respect to prevailing car prices, incomes and so on. At this stage, however, they are taken as exogenous. An attempt to show what determines their level is made later.

* Two versions of relative price of petrol were tried; PGt, that is average weighted price of all grades and P2t, that is average weighted price of "premium" petrol.
4.5 Regression results

Again two mathematical forms, with the variables expressed in deviations from their mean values, were tried as approximating the complex mathematical form of hypothesis A, that is linear and linear in logarithms forms. The results, from the point of view of the signs of coefficients as well as their statistical significance, were virtually the same. Since the coefficients of the double logarithmic form, representing the relevant elasticities, are easier to interpret, only the estimates relating to this form are presented (see tables 10 and 19).

4.6 Evaluation of the estimates

Looking at the results obtained one can see that in both tables four out of five coefficients have the signs expected on a priori grounds. The price elasticity (both versions) is negative, and the income, private stock and engine capacity elasticities are positive as one would have expected. This is not the case though for the commercial car stock variable \((SC_t)\). Its coefficient is not in accordance with a priori expectations. One would expect that an increase in the stock of commercial goods vehicles would bring an increase in the quantity demanded of petrol.

* All data used in this chapter along with their sources are given in the Appendix. 
### TABLE 18

U.K. Market Demand for Petrol 1955 - 1973

**Hypothesis A.1** [with total annual average price of petrol \((P_G_t)\)].

(Variables in deviations from their mean value)

\[
\ln Q_{tt} = a_1 \ln (P_G_t) + a_2 \ln (YPK_t) + a_3 \ln (SP_t) + a_4 \ln (SC_t) + a_5 \ln (EC_t)
\]

Elasticities:  
\[
\begin{align*}
a_1 & = -0.480 \\
a_2 & = 0.312 \\
a_3 & = 0.852 \\
a_4 & = -0.445 \\
a_5 & = 1.164 \\
\end{align*}
\]

\[
t-values \ (1.635) \ (0.531) \ (5.447) \ (1.782) \ (1.881)
\]

\[
R^2 = 0.993 \\
D = 1.25
\]

### TABLE 19

U.K. Market Demand for Petrol 1955 - 1973

**Hypothesis A.2** [with annual average price of premium petrol \((P^*_t)\)].

(Variables in deviations from their mean value)

\[
\ln Q_{tt} = b_1 \ln (P^*_t) + b_2 \ln (YPK_t) + b_3 \ln (SP_t) + b_4 \ln (SC_t) + b_5 \ln (EC_t)
\]

Elasticities:  
\[
\begin{align*}
b_1 & = -0.390 \\
b_2 & = 0.366 \\
b_3 & = 0.834 \\
b_4 & = -0.464 \\
b_5 & = 1.065 \\
\end{align*}
\]

\[
t-values \ (1.302) \ (0.596) \ (5.145) \ (1.762) \ (1.886)
\]

\[
R^2 = 0.993 \\
D = 1.33
\]
Several reasons may be offered to explain the disappointing performance of variable $SC_t$. First, it is possible that the way it was approximated (see page 112 and tables 15 and 16) may not be appropriate. It might be that some goods vehicles under $1\frac{1}{2}$ tons unladen weight are diesel powered. If this number is significant our approximation to $SC_t$ will overestimate its size. On the other hand, if a significant number of goods vehicles over $1\frac{1}{2}$ tons unladen weight are petrol powered then our $SC_t$ variable will underestimate the real stock of petrol driven goods vehicles. It might also be that the (unknown) real stock of petrol driven commercial vehicles has remained fairly constant over the period under consideration. Consider for example the hypothetical situation where this category did remain constant as a result of the considerable switch over of commercial customers towards diesel driven vehicles.* In this case, consideration of this variable in the relationship formulated would be equivalent to trying to determine the influence on the demand for petrol of a factor that showed no variation over the period under consideration. Such a possibility may not be as unrealistic as it sounds. A look at table 13 showing consumption of petrol by end

* Taking into account their average consumption characteristics as well, that is expressing the stock in terms of "consuming equivalent units".
use, suggests that consumption by goods vehicles remained remarkably constant over the period 1955-1973. But since the quantity consumed as postulated is just the joint effect of the rate of utilisation, the average consumption characteristics and the relevant stock of vehicles, the relative constancy of the quantity of petrol attributed to this category of vehicles may only be due to rather peculiar changes in those factors. Unfortunately, for reasons provided earlier, no further improvement may be made towards a more successful approximation of the "commercial" part of the postulated relationship.

Second, the degree of collinearity between $SC_t$ and the other variables included in the equation is quite high (table 20) and this, particularly in cases of errors of specification (that are almost unavoidable), might be the source of the unexpected estimate of the elasticity of $SC_t$. Upon these considerations $SC_t$ was dropped from the equations.

**TABLE 20**

Correlation coefficients (r's) between $SC_t$ and each of the explanatory factors in hypothesis A.

<table>
<thead>
<tr>
<th>$PC_t$</th>
<th>$P2_t$</th>
<th>$YPK_t$</th>
<th>$SP_t$</th>
<th>$IC_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$SC_t$</td>
<td>-.904</td>
<td>-.92</td>
<td>.952</td>
<td>.947</td>
</tr>
</tbody>
</table>

The above decision implies that it is likely that the reliability of the estimates will be increased if it is assumed that:

Variations in the quantity consumed of petrol $(Q_t)_t$ may be explained in terms of variations
in petrol price ($p_{it}$), income per capita ($y_{it}$),
engine capacity ($c_{it}$), and stock of the most
predominant category of petrol driven motor
vehicles, that is private cars and vans ($s_{it}$).

This constitutes the next hypothesis to be tested
(hypothesis B). Hypothesis B may be formulated in sev­
eral different ways, depending on how the relevant ex­pla­
natory factors enter the postulated relationship.

First (with the variables, as before, expressed in
logarithmic form and in deviations from their mean values),
as:

\[ B_1: \ln(Q_t) = a_1 \ln(p_{it}) + a_2 \ln(y_{it}) + a_3 \ln(c_{it}) + a_4 \ln(s_{it}) + \ln \epsilon \]

Second, the private stock variable ($s_{it}$) may be ex­
pressed in terms of "equivalent units" after multiplying
the number of private cars (in physical units) by the ave­
rage engine capacity ($c_{it}$) of the population of cars
for every period, and dividing the resulting series by
1000 c.c.* The series obtained will be the stock of pri­
vate cars expressed in "1000 cc car equivalents". In
this case one assumes that:

\[ B_2: \ln(Q_t) = a_1 \ln(p_{it}) + a_2 \ln(y_{it}) + a_3 \ln(s_{it}) + \ln u_t \]

where

\[ \tilde{s}_{it} = \frac{s_{it} \cdot c_{it}}{1000} \]

* This number, being a conventional measurement, may be
set at any level. The argument remains the same.
Third, recall that in section 4.3, where the relationship between consumption characteristics (expressed in miles per gallon) and engine capacity was tested, it was found that a 1% increase in engine capacity of a car was on the average associated with an approximate .5% decrease in miles given per gallon or, what amounts to the same thing, with a .5% increase in gallons per mile. If, using this extraneous information, it is assumed that such a relationship holds for the population of cars, one may postulate that:

\[ B_3: \ln \tilde{Q}_{tt} = a_1 \ln(W_{it}) + a_2 \ln(YPK_t) + a_3 \ln(SP_t) + \ln v_t \]

where:

\[ \ln(\tilde{Q}_t) = \ln(Q_{tt}) - .5\ln(\tilde{G}_t) \]

Estimation of the various versions of hypothesis \( B^* \) gave the results reported in tables 21-26.

* Given the relative constancy of consumption by goods vehicles, another reasonable formulation would be to redefine the dependent variable as \( (Q_{tt} - K) \) where \( K \) (a constant) stands for consumption by goods vehicles. This is done in chapter 5.
### Table 21

**U.K. Market Demand for Petrol, 1955 - 1973**

**Hypothesis B. 1a**  
(with total annual average price of petrol, $P_G_t$)

\[
\ln Q_{tt} = a_1 \ln(P_G_t) + a_2 \ln(YPK_t) + a_3 \ln(SP_t) + a_4 \ln(CC_t) + \ln e_t
\]

Variables defined in deviations from their mean observed value.

<table>
<thead>
<tr>
<th>Elasticities</th>
<th>$a_1$</th>
<th>$a_2$</th>
<th>$a_3$</th>
<th>$a_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimates</td>
<td>-.389</td>
<td>-.350</td>
<td>.970</td>
<td>2.002</td>
</tr>
<tr>
<td>$t$-values</td>
<td>(1.251)</td>
<td>(.714)</td>
<td>(6.376)</td>
<td>(4.625)</td>
</tr>
</tbody>
</table>

$R^2 = .992$

D-W statistic = 1.253

### Table 22

**U.K. Market Demand for Petrol, 1955 - 1973**

**Hypothesis B. 1b**  
(with annual average price of premium petrol, $P_2_t$)

\[
\ln Q_{tt} = a_1 \ln(P_2_t) + a_2 \ln(YPK_t) + a_3 \ln(SP_t) + a_4 \ln(CC_t) + \ln e_t
\]

Variables defined in deviations from their mean observed value.

<table>
<thead>
<tr>
<th>Elasticities</th>
<th>$a_1$</th>
<th>$a_2$</th>
<th>$a_3$</th>
<th>$a_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimates</td>
<td>-.253</td>
<td>-.244</td>
<td>.940</td>
<td>1.908</td>
</tr>
<tr>
<td>$t$-values</td>
<td>(.814)</td>
<td>(.449)</td>
<td>(5.833)</td>
<td>(4.312)</td>
</tr>
</tbody>
</table>

$R^2 = .991$

D-W statistic = 1.362
### TABLE 23

**U.K. Market Demand for Petrol, 1955 - 1973**

**Hypothesis B. 2a**

(with total annual average price of petrol, \(P_{Gt}\))

\[
\ln(Q_{tt}) = a_1 \ln(P_{Gt}) + a_2 \ln(YPK_t) + a_3 \ln(SP_t) + \ln u_t
\]

Variables defined in deviations from their mean observed value.

**Elasticities**

<table>
<thead>
<tr>
<th>El 1</th>
<th>El 2</th>
<th>El 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimates</td>
<td>-.008</td>
<td>.353</td>
</tr>
<tr>
<td>t-values</td>
<td>(.023)</td>
<td>(.640)</td>
</tr>
<tr>
<td>(R^2)</td>
<td>= .986</td>
<td></td>
</tr>
<tr>
<td>D-W statistic</td>
<td>= 1.106</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 24

**U.K. Market Demand for Petrol, 1955 - 1973**

**Hypothesis B. 2b**

(with annual average price of premium petrol, \(P_{2t}\))

\[
\ln(Q_{tt}) = a_1 \ln(P_{2t}) + a_2 \ln(YPK_t) + a_3 \ln(SP_t) + \ln u_t
\]

Variables defined in deviations from their mean observed value.

**Elasticities**

<table>
<thead>
<tr>
<th>El 1</th>
<th>El 2</th>
<th>El 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimates</td>
<td>.064</td>
<td>.442</td>
</tr>
<tr>
<td>t-values</td>
<td>(.180)</td>
<td>(.734)</td>
</tr>
<tr>
<td>(R^2)</td>
<td>= .986</td>
<td></td>
</tr>
<tr>
<td>D-W statistic</td>
<td>= 1.204</td>
<td></td>
</tr>
</tbody>
</table>
TABLE 25

U.K. Market Demand for Petrol, 1955 - 1973

Hypothesis 6. 3a
(with total annual average price of petrol, \( P_0^t \))

\[
\ln(\bar{Q}^t) = a_1 \ln(P_0^t) + a_2 \ln(YPK_t) + a_3 \ln(SP_t) + \ln v_t
\]

Variables defined in deviations from their mean observed value.

Elasticities \( a_1 \quad a_2 \quad a_3 \)

Estimates \(-.252 \quad .665 \quad .792\)

\( t \)-values \((.556) \quad (1.104) \quad (5.003)\)

\( R^2 = .987 \)

D-W statistic = 1.304

TABLE 26

U.K. Market Demand for Petrol, 1955 - 1973

Hypothesis 6. 3b
(with annual average price of premium petrol, \( P_2^t \))

\[
\ln(\bar{Q}^t) = a_1 \ln(P_2^t) + a_2 \ln(YPK_t) + a_3 \ln(SP_t) + \ln v_t
\]

Variables defined in deviations from their mean observed value.

Elasticities \( a_1 \quad a_2 \quad a_3 \)

Estimates -.116 .754 .780

\( t \)-values \((.259) \quad (1.137) \quad (4.732)\)

\( R^2 = .987 \)

D-W statistic = 1.437
A cursory look at the results derived suffices to show that hypothesis B did not lead to any significant improvement over hypothesis A, despite the apparently reasonable formulations.

The price coefficients in all but one case (B.2b) assume the correct sign. However, in only one case (B.1a) does the value of the coefficient exceed the value of its standard error.

The performance of the income coefficient is even worse. In two equations (B.1a and B.1b) it appears with a negative sign, implying an inverse relationship between quantity demanded and income. Intuitively, such a conclusion seems unrealistic. In all other cases its sign is in accordance with a priori expectations but in only two cases (B.3a and B.3b) does its magnitude exceed the value of the corresponding standard error.

In all cases the private stock and engine capacity coefficients exhibit the correct signs and they are statistically significant. Nevertheless, the magnitude of their elasticities in cases B.1a and B.1b seem unreasonably high. When the influence of average engine capacity is examined indirectly (equation 2.2a and 0.3b) the stock of cars coefficient appears more reasonable.

The overall conclusion seems to be that the estimates obtained are very sensitive to different formulations, since their values change rather drastically as a result of alternative formulations. This instability is likely
to be due either to the usual pathological features of
time series analysis, namely multicollinearity or to the
way the problem was approached.

As to the first possibility, it is generally accepted
that "there is no known device to cure multicollinearity".*
However, attempts aiming at overcoming the problem have
never stopped and here two methods that have been pro­
posed may be mentioned:**

i) Combination of cross-section observations with time
series data (by dividing the United Kingdom, for example,
into its four constituent parts). Unfortunately, most of
the required information does not exist in the desired
form.

ii) Introduction of additional equations in the
model.

"Multicollinearity may be overcome if we
introduce additional equations into our
model to express meaningfully the relationships
between the multicollinear X's. When looking
at the set of explanatory variables one is able,
in most cases, to find relationships between
the X's (and other new variables) which
make economic sense. By explicitly formulating

* J.S. Cramer, op. cit., p. 102.

** For a comprehensive summary of other attempts see
these relationships one can form a simultaneous-equation model which, ...

... can be estimated with a simultaneous equation technique". 

The second possibility is a more fundamental one and amounts to questioning the value of single equation models in the case of energy products. Although simple to work with, single equation models are inevitably, reduced forms of more complex systems via which an attempt is made towards approximation of reality. In the case of products that are perishable and provide satisfaction directly, on the assumption that supply considerations may be neglected (see page 51), single equation models would be legitimate and possibly the only choice available. This does not seem to be so in the case of products that do not provide direct satisfaction and where demand for technical reasons, depends to a significant extent on the underlying stock of the relevant consuming equipment. Here, the influences of prices and income has to be investigated bearing in mind the possibility of the multiple choices with which the consumer is faced. Moreover, technological considerations could provide an additional constraint of significant analytical value. These ideas, that are dictated by the two possibilities mentioned above, may be inves-

tigated through the formulation of an equation system. This is the object of the subsequent chapter.

Before we move on to discuss this problem, however, we should note that the comments relating to the practical usefulness of single equations are not inconsistent with our previous analysis about identification (page 51). It was argued there that since price could be considered as an exogenous variable, a demand-supply model was not required. Upon this consideration, we went on to recognise that the source of trouble of the naïve price income model was the neglect of stock considerations. These were taken into account by the introduction of stock (and other) variables which, at that stage, were assumed exogenous (see page 118). It is precisely the explicit recognition that these variables are endogenous (that is, generated by some underlying structure) that creates the need for a system of equations.
Chapter 5

A Multi-equation Model of the Demand for Petrol

5.1 Introduction

In the light of the models postulated previously and the results obtained, the next model to be formulated is based on the following considerations:

i) If the model is to be of some practical value, namely to be used for policy and forecasting purposes, separation of the influences of economic variables such as income and price of petrol into "direct" and "indirect" effects is necessary. The policy maker might like to know not only the overall influence of a price change on the quantity demanded of petrol but also how this change might affect consumers' decisions at different but strictly related behavioural levels, given the absolute technological complementarity between car use and petrol consumption. A drastic price increase through the imposition of a high tax per gallon of petrol might lead to a reduction in the rate of utilisation of the existing car stock. But it might as well have a considerable influence at the stage of purchasing a car. If the prevailing price of petrol is considered to be "high" and tends to remain so, consumers might show a preference for smaller cars or they might even postpone the purchase of a car. This in turn will tend to reduce the rate of growth of the existing car stock and consequently the demand for petrol. All these are very important structural changes which may be shown in a multi-equation framework, whereas a static single equation model is unlikely to be able to reveal them.
ii) For forecasting purposes it is rather desirable to express the mechanism underlying all these decisions in terms of predetermined variables, that is exogenous (such as prices and income) and lagged dependent variables where this seems to be appropriate. Because if, as has been argued*, some of the explanatory variables of the single equations tested previously (for example, stock of cars in use) are probably more difficult to forecast than the dependent variable (petrol demand) the practical usefulness of the model will be limited.

The reasons advanced above suggest that a model explicitly taking into consideration how consumers might be influenced at different stages of their decision making is appropriate. Although little relevant work has been done, the appropriateness of multi-equation models has been implicitly or explicitly recognised by students in the field of demand for energy products. Waverman, for example, points out that "in estimating the demand for electricity as a direct function of say real income and relative prices of fuels, one is implicitly suggesting that electricity demand is derived from the use of goods whose determinants themselves are real income and the relative prices of fuels"**

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* See criticism of Cangelosi's study (page 73).

It is reasonable, though, to expect that other variables such as the price of consuming equipment, credit conditions and the like might also play an important role in the determination of purchases of fuel consuming equipment. In such a case a single equation model, which is just the reduced form of a system of two equations - the first of which determines the rate of purchase of goods, which with fuel input provide services, and the second determines the amount of fuel input utilised in the use of these goods - is likely to be inappropriate. Everyone familiar with empirical work knows that single equation models where a large number of explanatory variables is involved very often lead to unsatisfactory estimates (for example, 'wrong' signs of coefficients and so on).

However, once the need for a multi-equation model is recognised another problem arises due to the nature of the commodities involved. Unlike say tea and sugar (both non-durables), in the case of cars and petrol a durable requires some non-durable in order to provide the desired services. But if for nondurables it seems reasonable to assume that consumers are able to adjust instantaneously their demand according to their incomes and the structure of relative prices, for durables this might not be the case. A static framework may be a good starting point and on the basis of it many interesting conclusions regarding consumers' behaviour may be drawn.

"But the simplest models though easy to work with, suffer from their very simplicity. It is our task as scientists to explain the phenomena
we study and to do so in as simple terms as we can. But we must always be on our guard against oversimplification and so when we have got a model which provides a good approximation in many situations we must try to improve it.... This process of going from simple models (first approximation) to more general ones (second and later approximations) is in fact the only way in which we can gain and extend useful knowledge".*

Uaverman gives a more specific form to the above general conclusion of Stone with respect to the demand for energy products suggesting that

"The simultaneous equation system should be estimated in dynamic form so as to distinguish the short term - assets fixed - from the long term - assets changeable - cases.... To derive simpler demand functions, not incorporating the simultaneous equation nature of fuel demand....is not only academically incorrect but foolhardy and dangerous".**

Thus, the model that is developed incorporates the assumption that at least with respect to demand for car ownership


** L. Uaverman, op. cit., p.p. 5-6.
and the associated technological characteristics of cars (engine capacity) consumers become involved in processes of adjustment with respect to changing circumstances. The model that was formulated to describe this process is explained briefly below.

5.2 The Stock Adjustment Model in general

Since a static framework cannot do justice in situations where durable goods are involved explicit dynamisation of the relevant demand equations is necessary.

The initial attempt in this direction through the introduction of a time trend is probably found in R. Stone.* This was followed by further refinements because a time trend seemed an inadequate variable to account for dynamic changes.

The common characteristic of dynamic models subsequently formulated is the reliance upon some sort of "stock adjustment mechanism" aiming to capture the peculiarities of the decision making process in the durable goods market, by postulating a reaction model of consumers' behaviour.

"The most publicized and successful reaction model (upon which most of the models rest implicitly or explicitly) is probably the stock adjustment model developed by Metzler and subsequently refined by Nurkse, Goodwin,

Lovell and others. Although the model was designed to explain inventory movements, its applicability can be extended by analogy to the case of durable goods in general and to the stock of appliances in particular.*

The original version of the stock adjustment model has its roots in the simple acceleration mechanism, the underlying assumption of which is that the existing gap between actual and desired inventory levels determines the amount of inventory change, that is

\[ I_t - I_{t-1} = \Delta I_t = \phi \left[ I_d^t - I_{t-1} \right] \]  

(5.2.1)

where the superscript \( d \) denotes the desired inventory.

The instantaneous adjustment nature of the above mechanism was questioned and this led to a reformulation through the introduction of a partial adjustment coefficient (\( \phi \)) that shows the proportion of the difference between actual \( (S_t) \) and desired \( (S_d^t) \) stock levels which is being made up during every period. Hence, the modified model takes the form

\[ V_t = S_t - S_{t-1} = \phi (S_d^t - S_{t-1}) \]  

(5.2.2)

(where \( V \) denotes the net addition to the stock) which is a finite approximation to the differential equation

\[ \frac{dS}{dt} = \phi (S_d^t - S_{t-1}) \]  

(5.2.3)

Furthermore, solving (5.2.2) for \( S_t \) one obtains the

* P. Balestra: op. cit., p. 45.
following equation:

\[ S_t = p S^d_t + (1-p)S_{t-1} \quad (5.2.4) \]

which cannot be tested empirically since it involves the unknown term \( S^d_t \). Behavioural assumptions can, however, be made. Several economic and other variables are usually considered as probable influencing factors and thus an equation that is ready (after specification of the mathematical form) for empirical investigation is derived of the form:

\[ S_t = \rho \left[ f(x_1, x_2, \ldots) \right] + (1-\rho)S_{t-1} \quad (5.2.5) \]

where the \( x_i \)'s are factors assumed to determine variations of the desired (or equilibrium) stock level.

Once the above model is accepted as a satisfactory approximation to consumers' behaviour, estimates of the elasticities corresponding to each explanatory factor may be obtained. Of course, if the desired stock remains constant over time, implying that the community has either reached a saturation level or that the factors determining \( S^d_t \) have reached a long run equilibrium value, \( S^d_t \) is asymptotically approached by \( S_t \), until the difference between actual and desired stock vanishes.

Now, given that the mathematical form of the postulated mechanism is at best an approximation of a much more complex reality, in empirical investigations an alternative form is tried which is the logarithmic version of the model presented above. This form implies that it is the ratio of desired to actual stock which is adjusted rather than their difference.

Having described the stock adjustment principle on which
an important part of the model to be developed depends, the next step is the choice of factors that are likely to influence the desired levels of variables that are subject to the postulated mechanism. These variables were taken to be:

1. The stock of private cars in use, \((SP)_t\).
2. The average engine capacity of the typical car, \((EC)_t\), and
3. The average rate of utilisation (mileage) of private cars in use \((M)_t\).

A separate behavioural equation is formulated where each one of the above appears as an endogenous variable, representing the outcome of economic decisions. Demand for petrol then is expressed as a function of decisions with respect to \(SP_t\), \(EC_t\) and \(M_t\).

5.3 Desired demand for car ownership

Although the determinants of the demand for cars, as indeed for any durable good, are in the words of Fisher and Kaysen, 'dishearteningly many'*, for the purposes of this study only those variables that on a priori grounds seem to be of primary importance are considered.

5.3.1 Income

Since a car is one of the most expensive durable goods, a measure of consumers' purchasing power should be included.

* F. Fisher and C. Kaysen, op. cit., p. 75.
in the equation for the desired demand for car ownership. The forms that have been used vary from model to model.

Roos and Szeliski use the income left after paying for basic needs such as food and rent, which they call "supernumerary" income.* Referring to the use of this type of income Evans believes that although this may have been a good idea for the interwar period, it is not relevant for the post-war years.** His argument is based on the fact that even during severe recessions personal disposable income hardly fell at all because of the stabilising influences of factors such as increases in unemployment compensation insurance, social security payments and so on. Furthermore, one may argue, since "basic needs" are very hard to define there is a large element of subjectivity in estimating supernumerary income.

Buxton and Rhys use an index of average income which they define as total net personal income (excluding persons with an annual income of less than £275) divided by the relevant

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A similar objection as above however may be raised with respect to this measure of purchasing power. Although it may be said that for every consumer a lower income can be assumed above which he is likely to decide to buy a car, this threshold value cannot be determined statistically unless one has a very deep knowledge of the income distribution and the consumption habits of the individuals which could only be obtained through extensive market research.

In the course of experimentation with various measures of consumers' purchasing power some authors use Friedman's 'permanent' or 'expected' income variable instead of the more conventional disposable income. The argument that the consumer makes his purchases considering his normal rather than his current income is the theoretical support for using permanent income as an explanatory variable. Such attempts have produced interesting results particularly when the objective was the explanation of variations in the stock of durables held. The subjective concept of permanent income is usually approximated empirically by an exponentially weighted average of disposable income. The consumer is assumed to give more weight to his current income and progressively smaller weights to his past incomes. Chow after constructing a permanent income variable in this way concludes that the

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stock of automobiles can best be explained by the relative price of cars and real expected income per capita, on the assumption of instantaneous adjustment of actual to desired stock.*

In most econometric studies on the demand for car ownership, real personal disposable income per capita is used and it is considered superior to other forms. Farrell uses an index of non farm personal disposable income per head.** Dicks - Mireaux and O' Herlihy find the use of real disposable income per head preferable to other forms.*** Odling - Smee recognises that in principle it is not obvious whether permanent or current real income should be used given that the purchase of a car means that probably more than one years' income has to be taken into account, but he uses current real disposable income in the equations he estimates.****

* G. Chow, op. cit., p. 164.
The choice is based on his belief that "to the extent that cars are considered luxuries, expenditure may have a high transient income elasticity".

Finally, Gross Domestic Product has been used as an activity variable, on the grounds that it might be more sensitive in representing fluctuations over the business cycle. This approach has been followed by a group of graduate students at the London Business School, in a project investigating the future of the U.K. car industry to 1975.*

The general conclusion that emerges from the previous studies is that the choice of the appropriate measure of consumers' purchasing power is mainly an empirical matter. Nevertheless a reduction in the number of alternatives is possible, and this depends on the object of the research. If one wants to explain car purchases then it seems that introduction of variations into the income series might increase the explanatory power of the postulated behavioural equation; subtraction of elements that are unlikely to be spent on cars and/or which move counter-cyclically (such as transfer payments) is a way of introducing the desired variation. If, however, one wishes to explain the determinants of the stock of cars in use, then real disposable income or permanent income seem to be more appropriate.

In the desired car ownership equation of our system real

disposable income is used. This is based on the following considerations:

i) the method of weighted averages which is used for the generation of the expected income series probably results in a 'smoothing' of fluctuations. This being the case the derived expected income series is likely to be correlated more closely with other variables in the estimating equation that tend to grow similarly over time, than a disposable income series.

ii) as far as is known, no serious attempt has been made in the U.K. towards the estimation of an expected income series.

The general Consumers price index (all goods and services) was used to deflate the personal disposable income series (see Appendix for data, definitions and sources).

5.3.2 Car prices

An index of the relative prices of cars was considered as the second important factor in the demand for car ownership equation.

The question of the appropriate price index is not a simple one and depends mainly on the purpose of the research. Farrell constructed a model assuming that the car market is a set of interrelated markets for close substitutes. The implication of this assumption is that aggregate demand will be affected as a result of changes in the structure of relative prices of cars of different age which will cause a movement of consumers from one market (including cars of age
say n) to another (including cars of age n+t). O'Herlihy is concerned with a period (1948-61) during the major part of which the British market was characterised by a chronic shortage of supply of new cars. For this reason he uses an index of prices which is the ratio of a used car price index to a new car price index. This variable (called index of Supply) is introduced into his analysis in the belief that "only by introducing the supply factor into the system will it be possible to produce reliable estimates of the demand relationships." However, when he comes to estimate the coefficients of the demand function (including seven variables) he reaches the rather disappointing conclusion that "the final result of rigorously applying a strict level of statistical significance would be an equation where the demand for cars is explained by a trend".

In this study since the objective of the particular equation under consideration is the explanation of variations in the total desired stock of cars no attempt was made towards the construction of a complicated car price index. The variable used was an index of cost of car purchases (both new and second hand) deflated by the consumers' price index in order to be expressed in real terms (see Appendix for data and sources).

The explanatory variables discussed so far, namely real disposable income and relative prices of cars have been found in "static" demand studies to explain most of the variation in demand for car stock. In some cases they have explained up to 95% of total variation. Chow in his static
model concludes that price and disposable income together explain 85-90% of the variation in the stock of cars. Using expected income instead of disposable income the explanatory power of his model goes up to 90-95%.

5.3.3 **Credit conditions**

Credit conditions constitute another major determinant in estimating demand functions for durables. According to Evans

"The use of credit enables an individual to save after he has purchased a durable good instead of before"

Such an interpretation gives rise to two different formulations of the role of credit.* According to the first, known as 'burden' theory, a debt contracted at any given time is a burden which has to be met in the future. Thus, credit availability results in a shifting of purchases but it does not by itself create additional demand. According to the second formulation, known as 'replacement theory' the use of credit facilities is a factor contributing to the increase of consumers' durables demand. The rationale behind this is that if an individual purchases a durable good, he is quite likely to replace it some time in the future. Therefore, the sooner a durable is bought due to more favourable credit

* A detailed explanation of the above two theories with some results of relevant empirical studies is given in Evans, op. cit., p.p. 153-164.
terms the earlier it is replaced in the future. This will add to the total stock of durables owned by an individual during his lifetime and through aggregation by the community as a whole.

What has been said above provides a theoretical explanation of the relationship between credit terms and stock levels of a durable. Turning now to the actual facts it can be seen from table 27 that approximately 25% of new cars were sold yearly on HP credit during the period under investigation. The number of used cars that are sold on HP terms has been approximately one million per year in recent years.* These figures are likely to underestimate the impact of credit sales since there is a substantial number of cars sold on bank credit but comprehensive data are not available for cars bought on other forms of credit.

However, impressive the above facts may be, the influence of credit conditions on car ownership demand has not been supported in empirical investigations. An attempt by NIESR research members** to introduce a variable measuring changes in HP conditions was followed by the conclusion that the annual demand data were not sensitive enough to detect any significant relationship between changes in such conditions and changes in the stock of cars. A possible explanation

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* D.G. Rhys, op. cit., p.229.

### TABLE 27

**Vehicles subject to hire purchase agreements in the U.K.**

* (Selected years)*

<table>
<thead>
<tr>
<th>Year</th>
<th>New car sales on HP credit in U.K. (thousands)</th>
<th>Total new car sales in U.K. (thousands)</th>
<th>HP sales as a percentage of total sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>1958</td>
<td>124.6</td>
<td>566.3</td>
<td>22.0</td>
</tr>
<tr>
<td>1963</td>
<td>263.1</td>
<td>1030.7</td>
<td>25.5</td>
</tr>
<tr>
<td>1965</td>
<td>318.8</td>
<td>1448.7</td>
<td>27.7</td>
</tr>
<tr>
<td>1968</td>
<td>296.7</td>
<td>1144.8</td>
<td>25.9</td>
</tr>
<tr>
<td>1970</td>
<td>261.1</td>
<td>1126.8</td>
<td>23.2</td>
</tr>
<tr>
<td>1972</td>
<td>359.2</td>
<td>1715.0</td>
<td>20.9</td>
</tr>
</tbody>
</table>

may be that the investigation was carried out on the basis of a relatively limited number of annual observations covering the period 1948-56. Since the period we investigate is considerably longer (1955-1973), an index of HP terms was used in this study. (See data Appendix). This was calculated as an annual minimum required deposit. There have been frequent changes in minimum deposits (see table 28) so the index for a given year is a weighted mean with weights equal to the number of months during which a particular deposit was applicable.
<table>
<thead>
<tr>
<th>Date of change</th>
<th>Minimum Deposit</th>
<th>Maximum period for repayment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(per cent)</td>
<td>(months)</td>
</tr>
<tr>
<td>1955, February</td>
<td>15.00</td>
<td>24</td>
</tr>
<tr>
<td>1955, July</td>
<td>33.33</td>
<td>24</td>
</tr>
<tr>
<td>1956, February</td>
<td>50.00</td>
<td>24</td>
</tr>
<tr>
<td>1956, December</td>
<td>20.00</td>
<td>24</td>
</tr>
<tr>
<td>1957, May</td>
<td>33.33</td>
<td>24</td>
</tr>
<tr>
<td>1958, October</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>1960, April</td>
<td>20.00</td>
<td>24</td>
</tr>
<tr>
<td>1961, January</td>
<td>20.00</td>
<td>36</td>
</tr>
<tr>
<td>1965, June</td>
<td>25.00</td>
<td>36</td>
</tr>
<tr>
<td>1965, July</td>
<td>25.00</td>
<td>30</td>
</tr>
<tr>
<td>1966, February</td>
<td>25.00</td>
<td>27</td>
</tr>
<tr>
<td>1966, July</td>
<td>40.00</td>
<td>24</td>
</tr>
<tr>
<td>1967, June</td>
<td>30.00</td>
<td>30</td>
</tr>
<tr>
<td>1967, August</td>
<td>25.00</td>
<td>36</td>
</tr>
<tr>
<td>1967, November</td>
<td>33.33</td>
<td>27</td>
</tr>
<tr>
<td>1968, October</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>1968, November</td>
<td>40.00</td>
<td>24</td>
</tr>
<tr>
<td>1971, July</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>1972, December</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>

5.3.4 Other variables

It was argued previously (page 13?) that the price of petrol might not only influence consumers' choice of the consumption characteristics of their cars but the desired stock itself, to the extent that a persistently high petrol price might constitute a barrier particularly for consumers who are in the lower income brackets. It was thought, therefore, that an index showing petrol price movements relative to the price of other forms of transport might be a reasonable variable to include in the demand for car ownership equation. The public transport price variable used to deflate the above series was an index of railway fares. Previous studies have shown* (and intuitively it seems reasonable to assume) that rail transport probably constitutes the only viable alternative to private transport if one takes into consideration factors such as convenience, speed of journey and so on.

The influence of population changes was investigated both directly and indirectly, that is as a separate variable and as a variable used to express real income in per capita terms (see Appendix for data and sources).

Any empirical investigation would be incomplete without a discussion of factors that relate to consumer attitudes. The influence of psychological and behavioural factors on demand is another point where economists' attention has

* See J. Ramsey et. al., op. cit., p. 502.
long been focused although such factors do not appear often in demand relationships because of the considerable difficulties associated with their quantification. A serious attempt in this direction in the U.S.A. has produced an index of consumers' attitudes and buying plans based on questionnaires about the relative financial position of people compared to previous years, expectations about their future situation, business conditions, price movements as well as whether 'times are good' for durable purchases.*

The importance of 'attitude variables' stems from the consideration that since stocks of durables are simply the sum of past purchases, factors that are responsible for the postponement of purchases will indirectly affect the stock of durables existing at a particular period. One would expect that in periods of recession there would be a decrease in the rate of growth of stocks of durables and especially cars, and that the opposite would be true in periods of prosperity. Not all this effect will necessarily be captured by the income variable.

In the U.K. such an index is not constructed on a regular basis although it would be most desirable as a variable

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* The survey has been developed by the Survey Research Center (SRC) at the University of Michigan. See, for example: G. Katona et al.: "Survey of Consumer Finances", Monograph 34, Survey Research Center, University of Michigan, 1964.
capturing general cyclical movements.*

5.4 Formulation of the demand for car ownership equation

Consideration of the variables discussed so far leads to the formulation of a desired demand for car ownership which in general form is as follows:

\[ SP^d_t = f( PC_t, Y_t, H_t, PR_t, Pt, e_{1t} ) = f(\cdot) \quad (5.4.1) \]

where:

- \( SP^d_t \) = desired stock of private cars
- \( PC_t \) = real price index of cars
- \( Y_t \) = real personal disposable income
- \( H_t \) = Index of credit conditions
- \( PR_t \) = price of petrol relative to an index of railway fares
- \( Pt \) = Home population

and \( e_{1t} \) = a disturbance term

Assuming now that the actual stock \((SP)_t\) adjusts to the desired stock \((SP^d)_t\) according to the relationship

\[ (SP)_t - (SP)_{t-1} = \rho[(SP^d)_t - (SP)_{t-1}] \quad (5.4.2) \]

* The Financial Times (FT) publish an index of consumer confidence which is the outcome of monthly surveys 'designed to find out how people feel about the future and their present financial position' (see F.T., March 20, 1978). However, these surveys started in 1970 and hence the number of observations is insufficient for the present analysis.
after appropriate substitutions one obtains

\[(SP)_t = \phi f(.) + (1-\phi)(SP)_{t-1} \quad (5.4.3)\]

which may be tested in both linear and logarithmic form as pointed out previously. All factors in (5.4.1) or combinations of them may be used as explanatory variables in the function \(f(.)\).

5.5 Demand for desired engine capacity

The second equation refers to the behaviour of consumers with respect to the desired consumption characteristics of cars as approximated by the average engine capacity of the population of private cars during a certain period.

The idea of including this equation in the system constitutes a natural extension of an earlier study by the author where the demand for petrol in the U.K. was investigated through a two-equation system, the first referring to the demand for petrol and the second to the demand for car ownership*. But it took a specific form on the basis of the study by Chow mentioned earlier. Chow believes that

"much misunderstanding of the automobile market has come from the tendency to "count cars"... The market does not consider all cars to be equivalent and .... its preferences as among

cars of different ages are remarkably stable over time. This...suggests that it is more meaningful to talk in terms of, say, 25 million new-car equivalents rather than in terms of 55 million cars on the road".*

For the purpose of his study he expressed the stock of cars in terms of new equivalent cars by a weighting system based on price information on cars during the base year, that considers an old car equal to half a new one if its price is half that of a new car.

For the purposes of the present study, as long as a car is on the road it consumes petrol and what is of interest is the distinction between, say, two cars from a petrol consumption point of view. It was recognised earlier (page 444) that several factors such as age, weight, engine capacity and so on provide reasons for the existing consumption differentials between cars; and of course it would be desirable to have data on these characteristics for different years. But information on the first two factors is, unfortunately, difficult to obtain. Hence, attention was focused on car engine capacity as a factor approximating the consumption characteristics of the car population, since relevant information is available (see data appendix). The results obtained when consumption characteristics were taken as a function of engine capacity (section 4.3) seem to support the view that this assumption is reasonable.

Turning now to the factors that are likely to influence

* G. Chow, op. cit., p. 150.
consumers when they are confronted with the choice of engine capacity one can think of several. The proportion of the price of a car, for instance, that may be attributed to differences in engine capacity would be an obvious variable to consider but difficult to quantify. The price of petrol is likely to play an important role as well, and here is where our attention is focused. Hence, for the explanation of variations in desired engine capacity a simple model is used in which the real price of petrol is the only explanatory variable although it is recognised that other variables might be significant. It is believed, though, that the simple model might be a reasonable approximation if the price of petrol continues to follow recent trends, in the sense that price will almost certainly have a gradual impact on desired engine capacity. For those who already possess a car, substitution by a 'smaller' one might imply a financial loss both from the car traded-in and from the car to be purchased as long as a general movement towards smaller cars results in a relative increase (decrease) of the prices of small (large) cars. However everyday experience confirms the observation that advertising gives more and more emphasis to the economy of a car, in terms of miles per gallon of petrol and this may well influence consumers.

According to what has been said the desired average engine capacity equation takes the form:

\[ EC_t^d = f(PG_t, e_{2t}) \]
where:
\[ EC^d_t = \text{desired average engine capacity} \]
\[ PG_t = \text{average real price of petrol (all grades)} \]
\[ \varepsilon_2t = \text{a disturbance term.} \]

Following the same steps as for the desired car ownership equation one obtains:
\[ (EC)_t = \lambda f_1(PG)_t + (1-\lambda)(EC)_{t-1} \]

5.6 Desired true rate of utilisation

In trying to approximate the behaviour of economic units with respect to the desired average rate of utilisation of existing private cars, two alternative hypotheses were considered. First, it was assumed that, as in the case of engine capacity and private car stock, some sort of adjustment is at work. Under such an interpretation, consumers' adjustment is supposed to be due to "habit formation or inertia, which is apparently a more widespread phenomenon".* In this particular case habit formation would mean that consumers do not adjust immediately their mileage according to changes in income and relative prices, but they are influenced as well by what their mileage has been in the more or less recent past. In other words it may be said that the consumer has built up a psychological stock of driving habits. This, being the case, his current mileage will be affected positively by his mileage in the past. Past mileage is taken into account by including lagged values of the relevant

* Houthakker and Taylor, op. cit., p. 10.
endogenous variable in the estimating equation. The positive relationship between current and past mileage means that with prices and income given the more someone has utilised his car in the past the more he will utilise it currently. Obviously, whether such an adjustment is at work is mainly a question that has to be supported by the existing evidence. For this reason the alternative hypothesis of instantaneous adjustment of desired to actual mileage was investigated as well.

A question arises as to the appropriate income variable to be included in the mileage equation. Ideally, since the endogenous variable is defined as average mileage per car, some sort of income per car owner would be desirable, but this is not possible due to lack of relevant information. Thus real personal disposable income per capita was used. Other formulations were also tried, by constructing an income per household series, the underlying assumption being that the household is the basic 'car owning unit'. Preliminary investigation showed, though, that the estimated income elasticity was not different from the income elasticity when income was defined in per capita terms, because of the lack of considerable variation in the average household size over the period 1955-73.

One would expect that economic units, in the process of trying to minimise costs, would tend to consider prices of various forms of transport. It has been argued elsewhere, and intuitively it seems plausible to assume, that rail transport is probably the most important alternative to
private transport, if matters such as speed of journey, convenience etc are taken into account. Thus a price index of railway fares \( (R_t) \) was considered along with the variables previously discussed (see data Appendix). Accordingly, the functional relationship between mileage and the explanatory factors is as follows:

\[
M^d_t = f_2 (PG_t, R_t, YPK_t, e_{3t}) = f_2(.) \quad (5.6.1)
\]

Assuming slow adjustment the estimating equation becomes:

\[
M_t = \Theta f_2(.) + (1-\Theta) M_{t-1} \quad (5.6.2)
\]

Under the assumption of immediate adjustment \((\Theta=1)\) the estimating equation is:

\[
M_t = f_2(.) \quad (5.6.3)
\]

5.7 The Demand for petrol equation

In the previous sections we were concerned with the construction of behavioural relationships aiming to provide an explanation as to how consumers' decisions are influenced at three different levels when they are faced with changes in the economic environment. In this section the demand for petrol is formed simply by bringing together in a functional relationship four different factors—namely the quantity of petrol demanded, \( (Q_{tt}) \), average private car mileage, \( (M_t) \), average engine capacity of private cars, \( (EC_t) \), and the number of cars in use during each year of the period under consideration, \( (SP_t) \). This may be written as:

\[
Q_{tt} = f_3 (M_t, EC_t, SP_t, e_{4t}) \quad (5.7.1)
\]

There are several points that are of interest in the
above relationship. First, it shows that variations in total quantity of petrol are explained in terms of variations of factors explaining private demand. This, in effect, implies that the second major part of total petrol demand (commercial demand) remains constant over the period 1955-73. As such, it does not contribute to the explanation of variations in total demand. It is assumed, in other words, that the relatively small variations of commercial demand around its historical mean value over the period 1955-73 (see table 13) are added to private demand. These residuals are small enough to ensure that the estimates of the coefficients of the above relationship should not be seriously distorted. Second, the terms appearing on the right hand side are not just the outcome of mathematical manipulations. The variables $M_t$ and $EC_t$ for instance have not been obtained by dividing total private mileage or total engine capacity of cars for a certain period by the number of cars in use during that period. The corresponding time series are official estimates based on road traffic and engine capacity sample surveys (see Appendix, for sources and definitions). By using data derived from different sources, an indirect check on the quality of the information used may be made. Third, one could characterise the above relationship as technological since although the factors appearing in it are the outcomes of economic decisions based on adjustment to changes in the economic environment, they cannot be considered, properly speaking, as economic variables themselves. It may be argued, therefore, that the formulated
relationship provides a link between an analysis exclusively based on economic considerations and an analysis that concentrates on technological variables ignoring the importance of economic factors. This, as stated at the beginning (page 5), was one of the challenging objectives of this study: to reconcile two different ways of approaching the problem of petrol and energy products demand. Fourth, a narrow consideration would seem to justify a simple OLS regression of $Q_{yt}$ on $M_{yt}$, $EC_{yt}$ and $SP_{yt}$. But careful examination shows that the last three variables cannot be considered as exogenous (which is one of the requirements of simple OLS). These variables would actually be exogenous if the information relating to them was the outcome of genuine experimentation, that is if we had forced the community of consumers to travel arbitrarily chosen distances and to use a certain number of cars with prespecified consumption characteristics, and then observed petrol demand. But in practice it is the consumers themselves who have determined the levels of $M_{yt}$, $EC_{yt}$ and $SP_{yt}$ according to principles underlying their behaviour. So, what has to be examined is how the set of variables appearing in the above relationship has been jointly determined. This may only be achieved by the construction of a system describing the relevant processes. Fifth, the nature of the relationship allows a non-abstract interpretation of the error term. The usual practice in applied research is the formulation of a reaction model where an error term assumed to have some desirable properties is inserted. One states or assumes that the error term is not correlated with the explanatory
variables in the equation, one hopes that this condition holds. In the demand for petrol equation there are reasons to believe that the error term is in fact correlated with the explanatory variables and thus an attempt to estimate this relationship without taking into account the joint determination of the variables appearing in it would produce unreliable estimates of the coefficients. The argument may be established by considering the equation:

\[ Q_{pt} = M_t \cdot c_{pt} \cdot SP_t \]  \hspace{1cm} (5.7.2)

where \( c_{pt} \) stands for the average consumption characteristics of the stock of private cars in use. One would expect, as pointed out earlier (page 155), that average car age (\( a_{pt} \)), weight (\( w_{pt} \)), engine capacity (\( EC_t \)), and so on are factors that determine variations in \( c_{pt} \), which is unknown, that is

\[ c_{pt} = f( EC_t, a_{pt}, w_{pt} \ldots \ldots ) \]  \hspace{1cm} (5.7.3)

Apart from the first explanatory variable on the right hand side of the above relationship nothing is known about \( a_{pt}, w_{pt} \) and possibly other factors that should have been included. Thus it is convenient to summarise the net influence of those factors by the introduction of an error term, \( e_t \).

Replacing \( a_{pt} \) and \( w_{pt} \) by \( e_t \) one obtains:

\[ c_{pt} = f( EC_t, e_t ) \]  \hspace{1cm} (5.7.4)

and therefore

\[ Q_{pt} = f( M_t, EC_t, SP_t, e_t ) \]  \hspace{1cm} (5.7.5)

Now, since

\[ Q_{Tt} = f( Q_{pt} ) \]  \hspace{1cm} (5.7.6)

one expects that
It is natural now to expect some correlation between car mileage and age of a car as well as between weight and engine capacity, to mention two obvious examples only. This, given that \( e_t \) stands for \( a_{pt} \) and \( w_{pt} \), renders the OLS method inappropriate for the estimation of the coefficients of the relationship. This conclusion is strengthened when the identification condition of the petrol demand equation is formally examined (sections 5.8 and 5.9).

The next step is the choice of the appropriate econometric technique for the estimation of the coefficients of the structural equations. Here, a large number of different combinations of the variables included in the behavioural relationships is possible, and as one would expect not all variables performed satisfactorily. Experimentation, for example, with the income variable expressed in 'per household' terms did not lead to any improvement of the results, a probable explanation being the lack of variation in the 'average family size' series used to transform population into number of households. Hence, this variable was dropped in favour of the more conventional real income per capita (YPK) variable. The results obtained when the price per gallon of premium petrol was used (the underlying assumption being that people are likely to respond to the most publicised grade of petrol) were virtually identical to those obtained when the overall average price of all grades was used. The credit conditions variable tried, although it showed a statistically significant negative relationship between
changes in minimum deposit required and variations in car ownership demand, had the rather undesirable effect of rendering the income variable statistically insignificant. Finally, the performance of the index of railway fares, whether used as a deflator or as a separate variable, was generally poor. Therefore, on the basis of economic, statistical and econometric criteria, the above variables were eliminated from the relevant equations.

In order to facilitate the presentation, the identification condition of the system is discussed in terms of the four finally modified equations that are as follows:

Equation 1: \( SP_t = a_0 + a_1(YPK)_t + a_2(PC)_t + a_3(SP)_{t-1} + a_4(P)_t \)

Equation 2: \( EC_t = b_0 + b_1(PG)_t + b_2(EC)_{t-1} \)

Equation 3: \( M_t = c_0 + c_1(PG)_t + c_2(YPK)_t \)

Equation 4: \( Q_t = d_0 + d_1(M)_t + d_2(EC)_t + d_3(SP)_t \)

5.8 Identification of the model

According to econometric theory, two conditions have to be satisfied for an equation to be identified. The first, known as the "order condition", requires that:

"For an equation to be identified the total number of variables excluded from it but included in other equations must be at least as great as the number of equations of the system less one".*

---

* A. Koutsoyiannis, op. cit., p. 342 gives an explanation of these concepts and a few examples, without using matrix algebra terminology.
Let \( G \) = number of equations in the model
\[ K = \text{number of all variables in the model (endogenous plus predetermined)} \]
and \( M_i \) = number of endogenous and exogenous variables included in equation \( i \), where \( i = 1, 2, 3 \) and 4.

Then according to the order condition:
\[ (K - M_i) \geq (G - 1) \]

In the case under consideration since \( G = 4 \), \( K = 10 \), \( M_1 = 4 \), \( M_2 = 3 \), \( M_3 = 3 \) and \( M_4 = 4 \) the above requirement is satisfied for all equations.

The second condition, known as the "rank condition" states:
"In a system of \( G \) equations any particular equation is identified if and only if it is possible to construct at least one non-zero determinant of order \( (G - 1) \) from the coefficients of the variables excluded from that particular equation but contained in the other equations of the model".*

In the model under study a possible set of parameters is given in the table below:

\[ \]

* A. Koutsoyiannis, op. cit., p. 343.

The term "rank condition" is due to the rank of the matrix of parameters of excluded variables. The rank of a matrix is the order of the largest non-zero determinant which can be formed from the matrix.
Variables $SP_t$, $EC_t$, $M_t$, $Q_t$, $YPK_t$, $PG_t$, $EC_{t-1}$, $PC_t$, $SP_{t-1}$, $P_t$

Equations

1. $a_1 0 0 0 a_2 a_3 a_4$
2. $b_1 b_2 0 0 0$
3. $c_2 c_4 0 0 0$
4. $d_3 d_2 d_1 1 0 0 0 0$

Following the above rule, the values of the non-zero determinants of order 3 that may be formed are:

1. $c_1$ (from columns 2, 6 and 4)
2. $c_2 d_1 + a_1 d_3$ (" " 1,5 " 3)

For equation
3. $b_2$ (" " 1,7 " 4)
4. $a_1 b_2 c_1$ (" " 5,7 " 6)

which implies that the rank condition for identification is satisfied as well.

5.9. Choice of the appropriate estimation methods*

As for the econometric techniques to be selected, for the behavioural equations 1, 2 and 3 the choice is straightforward. Since no endogenous variables appear on their right hand side use of OLS is legitimate. However, equations 1 and 2 were derived on the assumption that some sort of adjustment is at work with respect to desired car ownership and desired engine capacity. In each case

* The discussion on this section is based on Johnston op. cit., chapter 10.
the transition from an equation which cannot be estimated to another including observable variables produced a lagged value of the endogenous variable. This raises some estimation problems that depend on the assumptions made concerning the relevant disturbance terms. Here the following simple possibilities may be distinguished:

i) The disturbance terms are normally and independently distributed (NID) and

ii) the disturbance terms follow a first order autoregressive scheme of the form:

\[ e_{it} = p_i e_{i,t-1} + v_{it} \]

where \(|p_i| < 1\) and the \(v_i\)'s are NID.

Under (i) the only complication in equations 1 and 2 is the presence of lagged endogenous variables as explanatory factors. In this case, as some Monte Carlo studies have shown, least squares still seems the best estimating technique.* Nevertheless,

"one is never on firm ground in specifying the existence and properties of disturbance terms... While there may well be cases where lagged \(Y\)'s and serially uncorrelated disturbances may be valid assumptions we must now extend the analysis to cover the case of lagged \(Y\)'s and serially correlated disturbances".*

This relates to (ii) above. The combination of lagged endogenous variables and serially correlated disturbances invalidates the desirable properties of the OLS estimators. Moreover in this case "the conventional D-W test is biased towards the value for a random disturbance".* In estimating equations 1 and 2 the view is adopted that "the D-W test is not applicable to an equation containing lagged (dependent) values among the explanatory variables".** This does not imply, though, that autocorrelation may be regarded as absent. Several suggestions and estimation methods have been put forward aiming at the detection of the unknown autocorrelation coefficient.*** All these methods rest upon some kind of optimisation search procedure and are time consuming, which limits the practical choice to the computational facilities available****.

For equation 4 the appearance of endogenous variables as explanatory factors requires another suitable technique, and instrumental variables (IV) or two stage least

** J. Johnston, op. cit., p. 309.
*** see A. Koutsoyiannis, op. cit., ch. 10 and J. Johnston, op. cit., ch. 10.
****In this study a computing program prepared by D.F. Hendry of the L.S.E. was used (see 'GIVE', op. cit.), a summary of which is given in the appendix.
squares (2SLS) would seem appropriate. As far as the (IV) method is concerned, some objections have been raised, the main being that the selection of predetermined variables to be used as instruments is to a certain extend arbitrary.

And

"It is clear that the value of the estimates will differ according to the set of instrumental variables chosen: to each choice of IV corresponds a different set of parameter estimates. The set of instrumental variables which we may choose is not unique. Our choice and hence the estimates are arbitrary, a fact that renders this method not particularly desirable".*

The 2SLS method chosen for the estimation of equation 4 has been accepted as the most important of the single equation techniques for the estimation of parameters of overidentified models. In simple terms, the method implies application of OLS in two stages. In the first, the endogenous explanatory variables are regressed against all predetermined variables in the system and their theoretical values are obtained. In the second, the dependent variable of interest is regressed against the theoretical values of the endogenous regressors and the remaining exogenous variables for the estimation of the structural parameters. The method seems to be in accordance with the philosophy underlying the model that has been formulated, which implies that at first consumers decide on the basis of the prevailing prices, income

* see A. Koutsoyiannis, op. cit., ch. 10 and J. Johnston op. cit., ch. 10.
and past experience about the current levels of mileage, 
engine capacity and the number of cars in use. Then varia-
tions in these levels determine, through a technological 
relationship, the level of petrol consumption in the cur-
rent period.

5.10 Estimation of the model

As pointed out previously, a fair amount of experimenta-
tion is required for the estimation of the behavioural 
equations of the system, aiming at the detection of those 
explanatory factors that seem to cause variations in the 
endogenous variables. Since this is essentially an empiri-
cal question, it was thought that an exhaustive report of 
the outcome of this experimentation would be pointless. 
Hence in this section only those results that were considered 
more satisfactory are presented, (table 29) and the discus-
sion that follows concentrates upon them (section 5.11). 
The time series of the variables employed in this section 
along with their sources are given in detail in the data 
appendix.

* A representative set of alternative formulations is given 
in the Appendix.
TABLE 29
U.K. Total Demand for Petrol: 1955 - 1973

Estimation of multi-equation system: Logarithmic version

Equation 1
(Variables in deviation form)

\[(SP)_t = 5.319(P)_t + .254(YPK)_t - .3172(PC)_t + .3548(SP)_{t-1}\]

t-statistics (2.417) (2.207) (3.339) (2.240)

\[R^2 = .999\]

D-W = n.a.*

Estimation method: OLS (corrected for autocorrelation)

Equation 2
(Variables in deviation form)

\[(EC)_t = - .093(PG)_t + .915(EC)_{t-1}\]

t-statistics (2.597) (19.258)

\[R^2 = .979\]

D-W = n.a.*

Estimation method: OLS

Equation 3
(Variables in deviation form)

\[(M)_t = .4097(YPK)_t - .220(PG)_t\]

t-statistics (3.519) (.968)

\[R^2 = .863\]

D-W = 1.503

Estimation method: OLS

Equation 4

\[(Qy)_t = - 3.425 + .619(M)_t + 1.408(EC)_t + .766(SP)_t\]

t-statistics (2.639) (7.531) (8.633) (32.933)

\[R^2 = .998\]

D-W = 1.63

Estimation method: TSLS

* n.a. = not applicable (see text, page 168).
5. 11 Evaluation of the estimates

Examination of the estimated coefficients (elasticities) shows that in general the results are plausible with regard to a priori (economic or otherwise) criteria. Changes in car prices \((PC)_t\) or the price of petrol \((PG)_t\) are negatively related, as one would expect, to changes in car ownership \((SP)_t\), average car engine capacity \((EC)_t\) and car utilisation \((M)_t\). Variations, on the other hand, in car ownership \((SP)_t\) and car utilisation \((M)_t\) are positively related to changes in income \((YPK)_t\) and population \((P)_t\). A similar argument is in order with respect to the signs of the coefficients of equation 4, which show that variations in average mileage \((M)_t\), engine capacity \((EC)_t\) or the stock of cars in use \((SP)_t\) are positively related to petrol demand \((Qy)_t\).

Turning to the examination of the individual behavioural equations the following may be noted:

All coefficients of equation 1 are statistically significant at 5%. The coefficient of the lagged stock variable \((SP)_{t-1}\) appearing on the right hand side of equation 1 provides an estimate of the speed with which the actual stock adjusts to the desired stock. Since according to what has been previously said this is equal to \((1-\varphi)\), \(\varphi\) being the speed of adjustment, it follows that almost 65% of the difference* between actual and desired stock is made up during

* Since the logarithmic version of the stock adjustment model is used, the word 'difference' refers to the logarithms of the desired and actual stock.
every period (year). The easiest way to think of the adjustment coefficient is in terms of the number of periods (years) that are required to make up certain proportion of the total difference between actual and desired stock. The number of years required to make up 65%, 88%, and 96% of the difference are shown in the following table. These calculations suggest that almost 96% of the gap is made up during a three year period. Such a conclusion seems to be in fairly close agreement with the one reached by Odling-Smee who, experimenting with quarterly data, found that 13 quarters are required to close 99% of the gap between actual and desired stock.

**TABLE 30**

Adjustment of actual stock to desired stock of cars

<table>
<thead>
<tr>
<th>Year</th>
<th>During period</th>
<th>Total</th>
<th>Remaining</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>65</td>
<td>65</td>
<td>35</td>
</tr>
<tr>
<td>2</td>
<td>22.75</td>
<td>87.75</td>
<td>12.25</td>
</tr>
<tr>
<td>3</td>
<td>7.96</td>
<td>95.71</td>
<td>4.29</td>
</tr>
</tbody>
</table>

The economic (income and price of cars) and demographic (population) variables, assumed to determine variations in the desired stock of cars, appear to influence current car stock. However, the income elasticity found in this study appears to be lower (0.254) than those reported by Odling-Smee (he reports income elasticities ranging from 0.37 to 0.42) while the price variable in our case appears to be a significant explanatory factor unlike the statistically
insignificant price variable of the above study.*

The coefficients of equation 2, which shows the effect of petrol price \((PG)_t\) changes on variations in the average engine capacity \((EC)_t\) of the car population, are also significant at 5%. In the short-run the price of petrol effect seems to be fairly small, given that, as the price coefficient indicates, a 1% increase in the real price of petrol will be followed by a less than 0.1% decrease in the average engine capacity of cars. This, however, is not a totally unrealistic result. Since a change in the average engine capacity of the car population will come about only through a change in the desired characteristics of new car registrations (that is, replacement plus new demand for cars), the depressing influence of petrol price increases will naturally be felt over a number of years, during which a new equilibrium with respect to car characteristics will be reached.

Utilisation of the estimated coefficients of equation 2 provides an estimate of such an equilibrium value. In order to calculate it, equation 2, which was estimated in deviation form, has to be expressed in absolute values. This gives:

\[
\ln(EC)_t = .94 - .093\ln(PG)_t + .915\ln(EC)_{t-1}
\]

Now, given that in equilibrium the average engine capa-

* Odling-Smee, op. cit., p. 197.
city of the car population in period t-1 will be equal to that in period t, one obtains the equilibrium value by solving the above equation with respect to $EC_t$:

$$(1-.915)\ln(EC^e) = .94 - .0931\ln(PG)_t$$

(where $e$ denotes equilibrium)

or

$$\ln(EC^e) = 11.059 - 1.094\ln(PG)_t$$

Replacing $(PG)_t$ by its value in 1974 (that is, the year of the first considerable price increase of petrol) and assuming that this may be taken as the equilibrium value prevailing in the future it turns out that:

$$\ln(EC^e) = 11.059 - 1.094(ln35.484)$$

or

$$EC^e = 1279.76$$

$\approx 1280$ c.c.

This calculation shows the considerable depressing influence of petrol price increases in the long-run, given that the figure of 1280 c.c. represents an almost 10% decrease over the 1973 average value of the engine capacity of the car population, which was approximately equal to 1400 c.c. However, the process of adjustment (as indicated by the coefficient of the lagged dependent variable, $(EC)_{t-1}$) appears to be extremely slow. In fact, assuming a round 10% (instead of 8.5%) adjustment during every period it turns out that a period of 10 years is required to close 65% of the gap between desired and actual levels of the average engine capacity of the car population.
Equation 3, shows that income \( (YPK)_t \) - significant at 5% - appears to play a more important role with respect to variations in the average distance \( (M)_t \) travelled by the average car than the price of petrol \( (PG)_t \) whose coefficient, as the \( t \)-value indicates, is almost equal to its standard error. Such a result though is not surprising given the relatively small variations in the real price of petrol during the period under consideration (1955-1973). Hence although pure statistical considerations would suggest dropping the \( PG \) variable from equation 3 as statistically not very significant (in fact it becomes statistically significant at the 20% level*), judgement would dictate that the estimated coefficient, if not increasing (in absolute terms) would at least become statistically more significant in periods of drastic price increases. Thus it was decided not to drop \( PG \) from the mileage equation.** However, this rather arbitrary decision does not seem unjustifiable in view of the outcome of a parameter stability exercise performed (see below).

* For 17 degrees of freedom and using the one tail test (see page 59).

** The practice of not dropping a coefficient when its value is equal to its standard error is not unusual. See P. Balestra, op. cit., Fisher and Kaysen, op. cit., and Houthakker and Taylor op. cit.
Investigation of whether the unsatisfactory performance of the price variable in the above equation was due to econometric problems (namely autocorrelation and multicollinearity) did not provide strong evidence that this might have been the case.

The value of the D-W statistic (=1.503), although between the lower ($d_L = 1.08$) and upper ($d_U = 1.53$) critical values at the 5% significance level (which, strictly, would imply that the test is inconclusive) was very close to the $d_U$ value. Hence apart from respecification of the equation through the inclusion of other explanatory factors (for example an index of railway fares), which turned out to be unsuccessful, no further attempt was made towards correcting for autocorrelation.

As for multicollinearity, it was argued earlier (page 61) that its ill effects would show up in the form of relatively large standard errors thus rendering the relevant coefficients statistically insignificant. And in fact this simplest possible criterion was adopted in deciding whether the estimates are distorted because of multicollinearity. However, an alternative test which may be taken to apply in the case of two explanatory factors only* has been

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* "....when there are more than two explanatory variables, we cannot simply look at the coefficients of correlation and conclude that the sample is not perfectly (or highly) multicollinear". J. Kmenta: "Elements of Econometrics", The Macmillan Co., New York 1971, p. 384.
proposed.* Accordingly, multicollinearity (as expressed by the correlation coefficient $r_{ij}^2$ of the pair of the explanatory factors in an equation) becomes a problem only if it is high relative to the overall degree of multiple correlation, $R^2$, that is if

$$r_{ij}^2 \geq R^2$$

For equation 3

$$r^2_{(PC)(YPK)} = 0.807 < R^2 = 0.863$$

As regards equation 4, one would expect that proportional changes in the rate of car utilisation $(M)_t$ or the stock of cars in use $(SP)_t$, ceteris paribus, would be followed by a less than proportional change in the total quantity of petrol demanded and in fact this turns out to be the case upon consideration of the relevant coefficients, which are highly significant as the values of the t-statistic indicate. Nevertheless, the coefficient relating to $(FC)_t$ seems rather high, and what is more important sharply contradicts the conclusion reached in section 4.3 (page 116). A probable explanation would be that variable $(EC)_t$ incorporates the influence of other factors such as average car age or weight that are not explicitly considered. Nevertheless, it is rather unlikely that their influence is so great as to justify the estimate obtained. Hence it was thought that such a proposition could be tested through

an alternative formulation of the dependent variable of equation 4. Given, as shown previously that the second major part of total petrol demand, that is commercial demand, remained remarkably constant over the period under consideration, the dependent variable may be redefined as total private demand, \( (Q_p)_t \). This was done by subtracting from \( Q_t \) the (constant) commercial part which was assumed to be 757,500 thousand gallons.* Thus the remaining part, \( Q_p \), was used as the dependent variable in equation 4 of the system.

Such a formulation, though, needs some further consideration. Recall that equation 4 was taken as a technological relationship, showing variations in petrol demand as a result of variations in average mileage, number of cars in use and their average engine capacity. A priori, one would expect that with \( SP_t \) and \( EC_t \) constant at any level a percentage increase in average mileage would bring an almost identical increase in private petrol demand. Doubling of \( M_t \), for example, with \( SP_t \) and \( EC_t \) constant would double the quantity of private petrol demanded. The same is true of course if changes in the stock of cars are considered with \( M_t \) and \( EC_t \) remaining constant. A similar

* The actual average annual commercial demand was \( 2.4827 \times 10^6 \) tons, and the average conversion factor 303.3 gallons/ton. The assumed values were \( 2.5 \times 10^6 \) tons and 303 gallons per ton respectively (see tables in Appendix).
argument though cannot be made for $EC_t$. The conclusion reached in section 4.3 may be considered as a "lower bound" of changes in consumption as a result of changes in engine capacity. This is because the relevant investigation, as far as the consumption data were concerned (miles per gallon), was based on manufacturers' figures that normally refer to more or less "ideal" conditions, and as such probably underestimate real petrol consumption.

Traffic conditions, as well as factors that due to lack of information were not considered explicitly in the model, may be expected to affect consumption characteristics in an upward direction, thus causing the coefficient of $EC_t$ to rise. However, although no guess may be made concerning the upper bound of this coefficient, it would seem reasonable that if the coefficient of $M_t$ and $S_t$ were close to unity for the reasons provided above, the coefficient of $EC_t$ would be more reliable.

Another equally important consideration is that given the technological nature of the demand for petrol equation, it follows that reformulation of the dependent variable as $Q_{pt}$ would suggest that the function should be constrained to pass through the origin. In other words it should be estimated without a constant term. In the hypothetical case where one of the major explanatory variables ($M_t$ or $S_R$) is equal to zero, one would expect that total private demand for petrol should be zero as well.

Reestimation of equation 4 using the TSLS method with total private demand as the dependent variable gave the
following results:

**Equation 4a:** Logarithmic version

\[ (Q_p)_t = (Q_{1-K})_t = 1.0119(M)_t + .6021(EC)_t + .9094(SP)_t \]

standard errors \( (.13792) \quad (.02125) \quad (.02606) \)

t-values \( (7.337) \quad (28.337) \quad (33.852) \)

\[ R^2 = .996 \]

D-W = 1.21

St. error of estimate of equation = .02992

Estimation method: TSLS

Consideration of the above estimates shows that the only slightly "weak" point in the results is the value of the D-W statistic. This does not provide evidence for non existence of autocorrelation (the test is inconclusive). Correcting for autocorrelation, using a search procedure technique, which is a feature of the computer program used, gave the following estimates:

**Equation 4b:** Logarithmic version

\[ (Q_p)_t = .8912(M)_t + .592(EC)_t + .945(SP)_t \]

standard errors \( (.13407) \quad (.01946) \quad (.02865) \)

t-values \( (6.64624) \quad (30.421) \quad (32.980) \)

\[ R^2 = .997 \]

D-W = 1.812

St. error of estimate of equation = .02668

Estimation method: TSLS

Of the previous two equations the latter may be considered slightly superior on the basis of both the value of the D-W statistic and the slightly lower standard error.
of estimate. Hence, it may be chosen as better explaining
variations in petrol demand in terms of variations in
the explanatory variables concerned. It is also interes-
ting to note that the coefficients of equation 4b are in
accordance with the a priori expectations stated above.
The coefficients of $M_t$ and $SP_t$ when the dependent vari-
ble is redefined as total private petrol demand $(Q_p)_t$
are very close to unity and the engine capacity $(EC)_t$
coefficient is just about 0.5.
A non-technical summary, conclusions and recommendations

In this study an attempt has been made to provide useful information relating to the demand for petrol in the United Kingdom, through a model building approach based on pragmatic considerations.

One of the main targets of such an attempt is to propose a different approach from that pursued in the existing literature, and one which, hopefully, apart from academic interest may be of some practical value as well. The latter consideration leads to the construction of a framework dictated by simplicity and supported by existing evidence.

One does not need to be an economist to say that the demand for an energy product such as petrol is simply determined by three factors: the average mileage per car, the average consumption characteristics of the typical car and the stock of cars in use in the community. These three factors, however, are the outcomes of economic behaviour reflecting adjustments to changes in the economic environment, as expressed primarily by changes in prices and income. Hence, the applied economist's task is to link the economic variables in such a way as to approximate the relevant processes through appropriately specified equations. The disaggregation proposed permits incorporation of the assumption that consumers are likely to be involved in processes of adjustment both with respect to the size of their cars and the number of cars in use. Moreover,
it provides another useful distinction: it is generally accepted in energy demand studies that the demand for an energy product is a derived demand, and hence strictly related to the underlying stock of consuming appliances. However, simple consideration of a stock variable in terms of natural units in use suffers from an obvious limitation: that is the underlying assumption that these units are homogeneous with respect to their consumption characteristics. Clearly, this is hardly a realistic assumption. Hence, explicit consideration of variables which distinguish between stocks of equipment consumption-wise is called for. In the case of petrol this was done by incorporating in the model a variable standing as a proxy for the consumption characteristics of the car population during every period.

Recognition that consumers' behaviour may be separated into three different levels (three behavioural equations) permits investigation of the influences of variations in the prices of the durables concerned as well as other variables or processes that are likely to play an important role; this is rather difficult within the framework of a single equation model. Such a separation dictates that the estimated elasticities should be interpreted accordingly. In the mileage equation, for example, the coefficient of the price variable shows the percentage change in the average car's rate of utilisation \((M)_t\), following a percentage change in the price of petrol \((PG)_t\). A similar interpretation is in order with respect to the remaining coefficients
of the behavioural equations. Note that such an interpretation is consistent with the derived demand nature of petrol. Consumers do not get direct satisfaction when they purchase petrol. Hence changes in the price of petrol affect their decisions as to the distances travelled by car. Considerable price increases may lead them to cut mileage associated with pleasure or similar trips.

The period under investigation showed that in general mileage (and through equation 4b, demand for petrol) is price and income inelastic. A 1% increase in the average price of petrol leads to a reduction in average mileage by 0.22%. From this an immediate policy implication could be derived. If the authorities' target is maximisation of total revenue from petrol, this may easily be achieved through tax increases given the insensitivity of petrol demand with respect to petrol price changes (although they could eventually find a price level at which demand becomes price-elastic). However if conservation is the target then this might better be achieved by imposition of lower speed limits. Such a conclusion is not so strange as it seems at first glance. For the average driver, insensitivity of desired utilisation (mileage) with respect to price changes (at least within the range of experienced price variations up to 1973) implies that a price increase is not followed by a drastic decrease in average car utilisation. In the extreme case, if average car utilisation were taken as totally unresponsive to price changes, it would mean that after a price change from $p_0$ to $p_1$ (with
the distance travelled at both price levels would be identical (say $M$), ceteris paribus. But distance travelled is simply the product of average speed, $\bar{v}$, times the time of travelling $t$. Therefore if the same distance were driven at two different speeds, say $\bar{v}_0$ and $\bar{v}_1$, one would have

$$M = \bar{v}_0 \cdot t_0 = \bar{v}_1 \cdot t_1$$

with $\bar{v}_0 > \bar{v}_1$ and $t_0 < t_1$

Now if lower average speed is associated with lower consumption of petrol per mile, this would imply that conservation could be achieved, in the short-run, by imposition of speed limits rather than tax increases.

The above proposition becomes of greater importance if, as equation 2 suggests, petrol price increases are to have some effect on car design. If the industry is not flexible enough to meet the changing requirements of consumers, it may be adversely affected by significant petrol price increases. Industry flexibility in this context should be taken to imply the period required for car and engine design changes, or technological developments leading to more economical cars. But

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* "Extensive data on the effect of driving speeds, stop-and-go driving, highway conditions and other factors on fuel economy have been developed... These data show that a typical auto has its maximum fuel economy at 30 m.p.h., which falls by 25% at 60 and 34% at 70 m.p.h." See T. Hill and B.J. Yudow (the engineering study reviewed in chapter 3), op. cit., p. 176.

† It is also possible that higher petrol prices would result in lower average speed and therefore lower petrol consumption.
efficient engine and car designs take time to be developed and technological developments, in the sense of energy-saving devices, take a long time to contribute. Hence, short-run policy aiming at conservation through tax increases might lead to consumers looking for more economical cars.

The industry's view on the probable effects of policies favouring the "small" car may best be given by the following quotations:**

"... the motor industry has high capital commitment to existing vehicle and engine designs. A sudden change in fiscal policy could be damaging to the motor industry and to our balance of payments by creating a new pattern of demand for which the industry is not geared........................................

.........................................................................................

"It is too early as yet to identify any clear movement of demand towards smaller vehicles in the new car market; there are signs, however, in the second-hand car market that the higher cost of fuel is causing a shift of demand towards the smaller option................................................

.........................................................................................

It is expected that there will be a downturn in

demand for the heavier motor car

This in itself will create problems for companies and it would be wrong in the present precarious state of the industry to exacerbate a situation already promising to be difficult, particularly as there would be no significant fuel saving in the short-term.

Another interesting feature of the model as a whole is that, despite the fact that the double logarithmic form employed implies constant elasticities, it clearly shows that with respect to petrol price changes long-run elasticities are likely to be greater than short-run elasticities. This may be seen by recalling that while in the short-run the price elasticity is the price coefficient in the mileage equation, in the long-run it is this effect plus the influence of price with respect to desired car characteristics.

However, a word of caution is in order with respect to the imposition of the double-logarithmic form for the estimation of the individual equations. Obviously, it would be rather unrealistic to think that the estimated elasticities are expected to remain constant for prolonged periods and more specifically periods of considerable petrol price increases. If one accepts this argument, then it follows that we might experience changes that are not taken into consideration in the model. For example, prolonged and considerable petrol price increases,
would probably have a depressing influence on the demand for car ownership as well. If petrol price increases push car utilisation rates below certain (and rather difficult to guess) levels, then some consumers will probably start wondering whether to have a car at all. This is because very low average mileage would imply not only very high variable (mainly petrol) costs but high total costs per mile as well.

The points raised above indicate that the demand for petrol function is a highly complicated relationship and the results derived should be interpreted as showing mainly qualitative information. The quantitative information provided by the results reported should therefore be interpreted with some care, that is as reflecting the kind of information used.

The variable, average mileage per car, for example, as pointed out earlier, is based on official figures derived from traffic counts and surveys; hence it was taken as representing the average value of the relevant distribution. To the extent that, due to sampling errors that are inevitable in surveys of this sort, the average value reported (and employed in this study) deviates from the true average mileage per car, the reliability of the relevant elasticities will be affected. The situation is similar but probably less serious with respect to the series relating to average car engine capacity and numbers of cars in use. The latter variable shows the number of private cars and vans licensed
and probably underestimates the real stock of cars in use as long as cars are used without being licensed. In employing the "stock of cars" time series one hopes that the percentage of road tax evasion does not vary violently from period to period. Nevertheless, it seems that the information reported in official documents may undoubtedly improve for investigation purposes. The MOT system (issue of car 'test certificate') may quite well provide the source of improvement as regards more precise information on car mileages, age, weight and so on, which will give investigators the opportunity to report more accurate estimates on which responsible policy recommendations could be based.

Finally a test is proposed on the stability of the estimated elasticities of the model or in other words on the overall performance of the model, in the form of a forecasting exercise. The elasticities derived from the sample period, 1955-1973, are used here to provide "forecasts" of the demand for petrol in 1974, 1975 and 1976. Strictly, a proper forecasting procedure would be one involving various assumptions about the levels of the exogenous variables in the model (sensitivity analysis), and comparison of the predicted levels of petrol demand to the actual demand that was unknown during the formulation of the various assumptions. In the present case, when the statistical part of this investigation started, the values of all variables in the system, up to 1974, were known. By the completion
of the study values up to 1976 inclusive became available, hence an evaluation of the predictive ability of the postulated mechanism is possible. Table 31 presents the values of predetermined (exogenous and lagged endogenous) variables used in the system for the years 1974, 1975 and 1976. The actual values of the endogenous variables for the same years are given in table 32. Finally, a comparison between actual and predicted values of the endogenous variables is made in table 33.

To facilitate the calculation the system of equations is presented below in non-deviation form (primes denote logarithms):

Equations

1. \((SP)'_t = -15.467 + 0.3548(SP)'_{t-1} - 0.3172(PC)'_t +
   + 0.254(YPK)'_t + 5.319(p)'_t

2. \((EC)'_t = 0.940 + 0.915(EC)'_{t-1} - 0.093(PG)'_t

3. \((M)'_t = 0.230 + 0.4097(YPK)'_t - 0.220(PG)'_t

4b. \((\chi_p)'_t = 0.8912(M)'_t + 0.5920(EC)'_t + 0.945(SP)'_t

Inserting the 1974-1976 logarithmic values of the endogenous variables and the corresponding logarithmic values of the lagged endogenous variables into the behavioural equations 1, 2 and 3, one obtains the values of the endogenous variables, which in turn are substituted into equation 4b.

The results are tabulated in table 34 (the symbol "A" means "predicted").
## TABLE 31

Values of predetermined variables used in the system

<table>
<thead>
<tr>
<th>Exogenous</th>
<th>Lagged Endogenous</th>
</tr>
</thead>
<tbody>
<tr>
<td>$PC(t) =$ Real price index of cars (1970=100)</td>
<td>$YPK(t) =$ Real income per capita (in £, 1970 prices)</td>
</tr>
<tr>
<td>$PC(1975) = 95$</td>
<td>$YPK(1975) = 743.808$</td>
</tr>
<tr>
<td>$PC(1976) = 95$</td>
<td>$YPK(1976) = 740.860$</td>
</tr>
<tr>
<td>( P(t) = \text{Home Population (millions)} )</td>
<td>( P(t) = \text{Real average price of petrol (in pence/gallon, all grades, 1970 prices)} )</td>
</tr>
<tr>
<td>$P(1975) = 55.962$</td>
<td>$P(1975) = 38.975$</td>
</tr>
<tr>
<td>$SP(t-1) =$ Stock of private cars and vans in use (thousands), lagged one period.</td>
<td>$EC(t-1) =$ Average engine capacity of car population (c.c.) lagged one period.</td>
</tr>
<tr>
<td>$SP(1973) = 13,805$</td>
<td>$EC(1973) = 1,405.00$</td>
</tr>
<tr>
<td>$SP(1974) = 13,948.24$</td>
<td>$EC(1974) = 1,417.60$</td>
</tr>
<tr>
<td>$SP(1975) = 14,061$</td>
<td>$EC(1975) = 1,425.37$</td>
</tr>
</tbody>
</table>
### TABLE 32

Actual values of the endogenous variables during the "forecast" period (1974 - 1976)

<table>
<thead>
<tr>
<th>SP(t) = Stock of private cars and vans in use (thousands)</th>
<th>EC(t) = Average engine capacity of car population (c.c.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP(1974) = 13,948.24</td>
<td>EC(1974) = 1,417.60</td>
</tr>
<tr>
<td>SP(1975) = 14,061</td>
<td>EC(1975) = 1,425.37</td>
</tr>
<tr>
<td>SP(1976) = 14,373</td>
<td>EC(1976) = 1,435.30</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>M(t) = Average mileage of private cars (thousand miles)</th>
<th>Q_p(t) = Total private petrol demand (million gallons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M(1975) = 8.6</td>
<td>Q_p(1975) = 4,022.3</td>
</tr>
<tr>
<td>M(1976) = 8.7</td>
<td>Q_p(1976) = 4,256.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q_T(t) = Total demand for petrol (million gallons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q_T(1974) = 4,866.9</td>
</tr>
<tr>
<td>Q_T(1975) = 4,756.9</td>
</tr>
<tr>
<td>Q_T(1976) = 4,979.3</td>
</tr>
</tbody>
</table>
# TABLE 33

**Comparison of actual and predicted values of petrol demand**

*1974 - 1976*

(million gallons)

<table>
<thead>
<tr>
<th>Actual</th>
<th>Predicted</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_p(1974) = 4,107.9$</td>
<td>$\hat{Q}_p(1974) = 4,130.8$</td>
<td>+0.557</td>
</tr>
<tr>
<td>$Q_p(1975) = 4,022.3$</td>
<td>$\hat{Q}_p(1975) = 4,080.6$</td>
<td>+1.449</td>
</tr>
<tr>
<td>$Q_p(1976) = 4,256.6$</td>
<td>$\hat{Q}_p(1976) = 4,177.5$</td>
<td>-1.858</td>
</tr>
<tr>
<td>$Q_T(1974) = 4,866.9$</td>
<td>$\hat{Q}_T(1974) = 4,888.3$</td>
<td>+0.440</td>
</tr>
<tr>
<td>$Q_T(1975) = 4,756.9$</td>
<td>$\hat{Q}_T(1975) = 4,838.1$</td>
<td>+1.707</td>
</tr>
<tr>
<td>$Q_T(1976) = 4,979.3$</td>
<td>$\hat{Q}_T(1976) = 4,935.0$</td>
<td>-0.890</td>
</tr>
</tbody>
</table>
TABLE 34

Predicted values of endogenous variables (1974 - 1976)

<table>
<thead>
<tr>
<th>Year</th>
<th>SP'</th>
<th>EC'</th>
<th>M'</th>
<th>Qp'</th>
<th>Qp</th>
</tr>
</thead>
<tbody>
<tr>
<td>1974</td>
<td>9.56051032</td>
<td>7.23905613</td>
<td>2.146907412</td>
<td>15.23397105</td>
<td>14,193.09 thousand cars</td>
</tr>
<tr>
<td>1975</td>
<td>9.56103318</td>
<td>7.239247752</td>
<td>2.133004966</td>
<td>15.22174504</td>
<td>14,200.51 thousand cars</td>
</tr>
<tr>
<td>1976</td>
<td>9.56288124</td>
<td>7.251734375</td>
<td>2.149084753</td>
<td>15.24521385</td>
<td>14,226.78 thousand cars</td>
</tr>
</tbody>
</table>

Moreover given that:

Private petrol demand ($Q_p$) = Total petrol demand ($Q_T$) - Commercial petrol demand ($Q_c$)

it follows that:

$$ (Q_T)_t = (Q_p)_t + (Q_c)_t $$

Recall however, that pragmatic considerations dictated that $Q_c$ (demand by goods vehicles) remained fairly constant during the observation period, and this (constant) quantity was taken to be equal to $K=757.5$ million gallons. Accordingly,

$$ (Q_T)_t = (Q_p)_t + K $$
and therefore:
\[ \hat{Q}_T(1974) = 4,888.3 \text{ million gallons} \]
\[ \hat{Q}_T(1975) = 4,838.1 \text{ " " } \]
\[ \hat{Q}_T(1976) = 4,935.0 \text{ " " } \]

A comparison of the values of private and total petrol demand predicted by the model with the actually recorded quantities may be considered as rather encouraging (see table 33). For 1974, in particular, it may be seen that the forecasting error is around a half percent. Note however, that such a surprisingly small error refers to the performance of the model as a whole. Consideration of the values predicted by the individual behavioural equations shows that the overall model prediction error is the net result of two opposing errors, mainly attributed to equations 1 and 2. For 1974, the demand for car ownership equation overpredicts by 1.76/ while the engine capacity equation underpredicts by a similar percentage (−1.677%).

For 1975 and 1976, the corresponding errors (calculated as previously from tables 32 and 34) are 0.992% and −1.017% for car ownership (equation 1) and −2.267% and −1.724% for average engine capacity (equation 2). The errors for equation 3 (mileage equation) were +0.682%, −1.860% and −1.414% for 1974, 1975 and 1976 respectively. It should be noted also that the values predicted by all equations for the years 1974-1976 refer to "point forecasts" and as such they are unnecessarily strict. From
a statistical point of view it would be proper to calculate confidence intervals around the point forecast value which in essence determine a whole range of prediction values (thus reducing the actual prediction error). Under such an interpretation the above results are not surprising. On the contrary, they may be utilised in order to draw further conclusions that may be of use for future research.

They are not surprising if it is remembered that 1974 was the year of the "3-day week" which hit the motor industry severely. On the other hand "The increase in imported oil prices has compounded an already serious economic situation in the U.K. The dual effect of the miners' industrial action and increased oil prices has been to depress seriously consumer demand during 1974 and 1975, directly affecting the demand for new vehicles in this period and leading to a postponement of some investment plans by the industry".* The stock of cars in use grew by only 1.2%, 0.81% and 2.22% in 1974, 1975 and 1976 respectively as compared to an average 7% per year during 1955-1973. This consideration indirectly establishes the importance of the hypothesised stock adjustment mechanism. It also suggests that reformulation of the model

so as to incorporate considerations relating to the supply side of the car market will improve its practical value and performance. Thus, further research is needed along these lines. Unfortunately, such an extension, given the relatively small number of available observations, could not be made. An attempt to increase the sample using quarterly data on all variables concerned proved to be impossible due to data unavailability. It is hoped that when new information becomes available this extension would then be possible to the benefit of everyone concerned with the problem of petrol demand and its interesting and important implications.
APPENDIX
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1955</td>
<td>6240</td>
<td>2648</td>
<td>3592</td>
<td>3782.5</td>
<td>309</td>
</tr>
<tr>
<td>1956</td>
<td>6324</td>
<td>2635</td>
<td>3689</td>
<td>3872.5</td>
<td>309</td>
</tr>
<tr>
<td>1957</td>
<td>5745</td>
<td>2250</td>
<td>3495</td>
<td>3293.5</td>
<td>309</td>
</tr>
<tr>
<td>1958</td>
<td>5624</td>
<td>2525</td>
<td>4099</td>
<td>4146.5</td>
<td>306</td>
</tr>
<tr>
<td>1959</td>
<td>7124</td>
<td>2480</td>
<td>4644</td>
<td>4648.5</td>
<td>306</td>
</tr>
<tr>
<td>1960</td>
<td>7625</td>
<td>2466</td>
<td>5159</td>
<td>5149.5</td>
<td>306</td>
</tr>
<tr>
<td>1961</td>
<td>8143</td>
<td>2515</td>
<td>5628</td>
<td>5643.0</td>
<td>303</td>
</tr>
<tr>
<td>1962</td>
<td>8565</td>
<td>2491</td>
<td>6074</td>
<td>6065.0</td>
<td>303</td>
</tr>
<tr>
<td>1963</td>
<td>9044</td>
<td>2456</td>
<td>6528</td>
<td>6544.0</td>
<td>303</td>
</tr>
<tr>
<td>1964</td>
<td>10012</td>
<td>2491</td>
<td>7521</td>
<td>7512.0</td>
<td>303</td>
</tr>
<tr>
<td>1965</td>
<td>10739</td>
<td>2453</td>
<td>8276</td>
<td>8222.4</td>
<td>301</td>
</tr>
<tr>
<td>1966</td>
<td>11322</td>
<td>2390</td>
<td>8932</td>
<td>8805.4</td>
<td>301</td>
</tr>
<tr>
<td>1967</td>
<td>12084</td>
<td>2415</td>
<td>9569</td>
<td>9567.4</td>
<td>301</td>
</tr>
<tr>
<td>1968</td>
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<td>Annual average car mileage thousand miles $M$</td>
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Sources of data: 1955 - 1973

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<td>(12)</td>
<td>Ministry of Transport Highway Statistics 1967 and &quot;Transport Statistics&quot;, Great Britain, 1964-74 where distributions of the car population according to engine capacity are given. Those distributions refer to Great Britain and start from 1960. The estimated means and</td>
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the extrapolated values prior to 1960 were assumed to be valid for the whole United Kingdom.

(13) : Passenger Transport in Great Britain, various volumes.

(14) : Calculated as (6) - (13).

(15) : This represents a price index of car purchases, new and second hand. Data for the period 1955-1964 were obtained from "Transport and Road Research Laboratory", TRRL Laboratory Report 650, p. 12. Information for the period 1964-1973, was taken from "Transport Statistics: Great Britain", 1964-1974, Department of the Environment, HMSO, July 1976, table 8, p. 8. Since the two series have different base periods, the year 1964 was used in order to link them. The resulting price index was subsequently expressed in real, 1970, terms.


(17) : Annual Abstract of Statistics, various volumes.

(18) : Calculated as (16) - (17).

(19) : This is a weighted average annual index of the minimum deposit required for the purchase of a car. The numbers of months during which a particular deposit was applicable were used as weights. The relevant information was obtained
(20) : Annual average car mileage based on traffic counts and surveys. Data for 1955-1957 were taken from: J. A. Dunn: "50-Point Traffic census: results for 1965", Road Research Laboratory Report No 45. Observations for 1959-1973 were obtained from:
" " : 1969, " 33, p. 47
" " : 1970, " 30, p. 46
" " : 1971, " 31, p. 42

1965-1973: AAS, 1975, table 257, p. 245 (Great Britain)

(22) : Calculated as \[ \left[ \frac{(11\times12)}{1000\text{c.c.}} \right] \]
### Data and Sources 1974-1976

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<th>CPI (8)*</th>
<th>PG (9)*</th>
<th>SP (11)*</th>
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* tonnes.

** Imperial gallons/tonne.
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1976: Figure assumed equal to that of 1975. |
| (18)'    | Calculated as \((16) \div (17)\). |
| (20)'    | 1974: Same as for (20).  
Data used in section 4.3 for the examination of the relationship between car engine capacity of car $i$ ($EC_i$) and miles per gallon of petrol ($z_i$) given by car $i$.

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Econometric Methodology

In this appendix a short description is provided of the econometric methodology adopted, when estimating the structural relationships of the model, to correct for autocorrelation.

It is assumed that the relationship to be estimated is given by the equation:

\[ Y_t = a_0 + a_1X_t + a_2Y_{t-1} + u_t \]  

(1)

with the error term assumed to follow a first-order autoregressive scheme:

\[ u_t = p u_{t-1} + e_t \]  

(2)

where \( e_t \) is a pure random error satisfying all the usual assumptions, and \( p \) is the autoregressive parameter. Lagging equation (1) by one period and multiplying through by \( p \) and then subtracting from (1) one obtains:

\[ Y_t = a_0(1-p) + a_1X_t - a_1pX_{t-1} + (a_2+p)Y_{t-1} - a_2pY_{t-2} + e_t \]  

(3)

where no autocorrelation exists. By employing an iterative procedure where a grid of values of \( p \) from -.9 to +.9 in steps of .1 is tried, one finds that value of \( p \) which minimises the residual sum of squares.
Alternative formulations of the behavioural equations

In this part a selected set of alternative formulations of the behavioural equations is given, according to which an evaluation of the relative performance of various variables tried may be made. Very briefly, the results may be summarised as follows:

Equation 1: The most striking feature is the change of the coefficient of the endogenous variables \((SP)_{t-1}\), when the influence of demographic factors \((P)_{t}\) is neglected. Its value in such a case is in the neighbourhood of .70 to about .80 implying extremely slow adjustment of actual to desired stock. This contradicts with other empirical findings (see page 173). The credit conditions variable \((M)(\text{formulation viii})\) although significant and in accordance with a priori expectations renders the income \((YPK)\) coefficient statistically insignificant.

Equation 2: Recall that inclusion of lagged endogenous variables in an equation renders the D.W statistic inapplicable. Here, an attempt to correct for autocorrelation (denoted by "*" or \("(EC)_{t-1}\), greater than unity. This contradicts with the hypothesis that the coefficient should lie between zero and unity. These formulations were rejected in favour of the uncorrected (for autocorrelation) version.

Equation 3: The "price of premium petrol" variable \((P2)_{t}\), gave results similar to those finally accepted with \((PG)_{t}\) as the relevant regressor (formulation iv). Definition of the income variable as FY3 (real family income excluding
expenditure on food and housing) gave also estimates close to those reported in chapter 5. The explanatory power of variables such as "changes in real personal disposable income per capita" (ΔRPI) or an "index of railway fares (R) was unsatisfactory (formulations ii, v, vi and x).
**ALTERNATIVE FORMULATIONS OF BEHAVIOURAL EQUATIONS**

Logarithmic Version (variables in deviation form)

**EQUATION 1: Car ownership**

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<th>((\bar{Y})_t)</th>
<th>((\bar{H})_t)</th>
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References


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