Demand Forecasts and Demand Elasticities for Australian Transport Fuel

Occasional paper

The study focuses on the current major transport fuels, which in 1988-89 accounted for 93 per cent of Australia's transport sector energy consumption: petrol (leaded and unleaded), automotive diesel oil, fuel oil and aviation turbine fuel. Major demand forecasts examined include those of the Australian Bureau of Agricultural and Resource Economics, the National Institute of Economic and Industry Research and the Australian Institute of Petroleum, based on forecasts by oil companies, to the year 2000. From an examination of these forecasts and derived own-price elasticities, the study concludes that only relatively large increases in fuel prices are likely to produce anything more than non-marginal reductionsin the levels of fuel demand.

Bureau of Transport and Communications Economics

Occasional Paper 103

Demand Forecasts and Demand Elasticities for Australian Transport Fuel

Report prepared by Professor David A. Hensher and Julie L. Young
Transport Research Centre, Macquarie University

ISSN 1032–0539
ISBN 0 642 16157 7

This publication is available free of charge from the Manager, Information Services, Bureau of Transport and Communications Economics, GPO Box 501, Canberra, ACT 2601.

Printed by the Department of Transport and Communications, Canberra

FOREWORD

The Bureau of Transport and Communications Economics commissioned the Transport Research Centre to examine various fuel demand forecasts for the transport sector up to the year 2000. This paper presents the results of the Transport Research Centre's study.

This report will be used to assist the Environment Group of the Australian Transport Advisory Council to formulate policies and possible strategies to reduce greenhouse gas emissions from Australian transport. Future projects of the Bureau are expected to continue to assist the Environment Group in its greenhouse gas emissions work.

The Transport Research Centre terms of reference were to examine fuel demand forecasts for land, sea and air modes, the validity of demand forecasts and energy consumption elasticities with respect to fuel prices, and the sensitivity of demand forecasts to any large shifts in fuel prices or the prices of alternative fuels, and to review the available research on long-term demand elasticities for transport fuels.

The views expressed in this report are, of course, those of the Transport Research Centre and should not be attributed to the Department of Transport and Communications or to the Bureau. The Bureau has, however, added a short addendum to chapter 4 examining the revised and extended forecasts published by the Australian Bureau of Agricultural and Resource Economics in January 1991.

M. R. CRONIN
Research Manager

Bureau of Transport and Communications Economics
Canberra

February 1991

ACKNOWLEDGMENTS

Many individuals and organisations gave generously of their time during January and February of 1990 to contribute information to this project and to comment on draft versions. I am especially indebted to David Greene and Frank Southworth of Oak Ridge National Laboratory in Tennessee, to the US Transportation Research Board Committee on Energy Conservation and Travel Demand, Barry Jones of the Australian Bureau of Agricultural and Resource Economics, Joy Ross of BP Australia, Richard Clarke and Anne Parsons of Shell Australia and Greg McColl of the University of New South Wales, Staff of the Bureau of Transport and Communications Economics and the Department of Transport and Communications gave freely of their time in supplying necessary background data and suggestions. In particular we are indebted to Mike Cronin, Phillip Ironfield, David Gargett, Stephen Wheatstone, David Cosgrove, Maurice Haddad, Bob Davenport and Rob Elder.

DAVID HENSHER
Transport Research Centre
Macquarie University
Sydney

CONTENTS

FIGURES

TABLES

ABSTRACT

The Bureau of Transport and Communications Economics commissioned the Transport Research Centre at Macquarie University to investigate various fuel demand forecasts for the transport sector, and in particular to identify the role of fuel prices in current forecasts.

The Transport Research Centre also examined the likely effects of alternative fuel pricing strategies on the overall demand for transport fuel, based on estimates of the long-term elasticities of fuel consumption with respect to fuel price.

The study focuses on the current major transport fuels, which in 1988–89 accounted for 93 per cent of Australias transport sector energy consumption: petrol (leaded and unleaded), automotive diesel oil, fuel oil and aviation turbine fuel. Major demand forecasts examined include those of the Australian Bureau of Agricultural and Resource Economics, the National Institute of Economic and Industry Research and the Australian Institute of Petroleum, based on forecasts by oil companies, to the year 2000.

From an examination of these forecasts and derived own-price elasticities, the study concludes that only relatively large increases in fuel prices are likely to produce anything more than non-marginal reductions in the levels of fuel demand.

SUMMARY

This study examines a range of fuel demand forecasts made by various agencies for land, sea and air transport, the validity of these forecasts and the own-price elasticities with respect to fuel prices assumed or implied by the forecasts, the sensitivity of the demand forecasts to large shifts in fuel prices as a whole, and the available research results on long-term demand elasticities for transport fuels. It focuses on current major transport fuels.

Major demand forecasts include those of the Australian Bureau of Agricultural and Resource Economics (ABARE), the National Institute of Economic and Industry Research (NIEIR) and the Australian Institute of Petroleum.

Since the consultant's report was completed, ABARE has published new projections. The Bureau of Transport and Communications Economics has included an addendum (to chapter 4) discussing the revised projections and the estimating techniques used by ABARE.

In 1989 ABARE forecast road transport energy consumption would increase at an average annual rate of 2.7 per cent from 1988–89 to 1999–2000. This was significantly higher than the NIEIR average rate of 1.97 per cent. ABARE's revised (1991) forecast is for road transport energy consumption to grow at 1.8 per cent to 2001–02.

Automotive petrol consumption was projected by ABARE in 1989 to increase at 1.4 per cent per year to 1999–2000, the average rate observed since the mid 1970s. This has been revised by ABARE in 1991 to about 0.9 per cent per year to 2001–02, and about 0.5 per cent from then to 2004–05.

The most rapid forecast growth is for automotive diesel (5.5 per cent per year, ABARE's 1989 forecast; 3.7 per cent, NIEIR), due to the assumed continuing substitution for petrol in commercial vehicles, and the continued growth of the road freight industry. ABARE's 1991 forecast is for a much lower rate of growth of about 2.5 per cent, with road transport use growing by 2.9 per cent per year, to 2004–05.

ABARE's 1989 projections for aviation fuel use had been revised upwards substantially from the Department of Primary Industries and Energy's *Energy 2000* report, increasing from 2.9 per cent to 3.9 per cent per year, due to the

downward revision in expectations of future oil prices and to substantial upward revisions in forecasts of growth in international passengers to and from Australia. ABARE in 1991 again revised the aviation forecasts upwards, with an average growth rate of 5.0 per cent to 2001–02.

The Transport Research Centre favoured the lower NIEIR forecast estimates for road transport diesel consumption and the higher ABARE 1989 estimates for aviation turbine fuel. Historically, however, the forecasts of these two fuels made by ABARE and NIEIR have tended to be sizeable underestimates of actual consumption.

For rail transport, while ABARE in 1989 predicted an increase in total fuel use, NIEIR foresaw a decrease. The Transport Research Centre leaned towards the ABARE (1989) forecasts.

The Transport Research Centre considered that LPG, natural gas and methanol had some potential as economically viable transport fuels in the 1990s, although there is likely to be little switching (other than from leaded to unleaded petrol), until the early decades of the 21st century.

The primary emphasis of this study was to identify the role of fuel price in current forecasts of transport fuels. The forecasts by the three major agencies — ABARE (1989), the Australian Institute of Petroleum and NIEIR — did not specify their econometric models in a form permitting identification of the role of fuel prices.

The Transport Research Centre estimated a series of models for road transport and aviation which are capable of deriving the required elasticities. The Transport Research Centre recommended the following fuel own-price elasticities:

Road passenger vehicles (5 year)	–0.66
Trucks (non-urban) (5 year)	–0.55
International aviation (1 year)	–0.12
Domestic aviation (1 year)	–0.18

It is the Transport Research Centre's strong belief that elasticity estimates derived directly from reduced form regressions over time-series of fuel demand, fuel price and a number of other commonly used exogenous variables, such as gross domestic product and fleet size, are significantly downward biased in contrast to estimates derived from a properly specified set of structural equations representing the real determinants of demand for travel, and hence fuel.

Current demand forecasting models are primarily driven by price and income. Big impacts on reducing greenhouse gas emissions will involve additional factors such as new technologies, promotion campaigns for new more efficient transport options, and research incentives, all of which are either poorly handled or unable to be handled in the current modelling and forecasting environment. More fundamental work is required on both model form and data before these models can be incorporated into an assessment of possible greenhouse gas emission reduction strategies in Australia.

Nevertheless, based on econometric simulation, it could safely be concluded that non-marginal reductions in greenhouse gases would require quite substantial non-marginal changes to fuel prices if a fuel tax were to be the sole or primary instrument of policy used to reduce fuel consumption.

CHAPTER 1 INTRODUCTION

The Bureau of Transport and Communications Economics commissioned the Transport Research Centre at Macquarie University to investigate fuel demand forecasts in the transport sector, and the likely effects of alternative fuel pricing strategies on the overall demand for transport fuels, as guided by estimates of long-term elasticities of fuel consumption with respect to fuel price.

The results of the investigation will be used as background material for advice to the Environment Group of the Australian Transport Advisory Council on possible impacts of alternative measures which may be adopted to reduce greenhouse emissions.

TRC's brief requires it to investigate the current status of transport fuel demand forecasts in Australia, giving particular attention to:

- the range of fuel demand forecasts made by various agencies, public and private, for land, sea and air services;
- the validity of the levels of demand forecast and any energy consumption elasticities with respect to fuel prices assumed or implied by the forecasts;
- the sensitivity of extant demand forecasts to any large shifts in fuel prices as a whole and also to shifts in relative prices of alternative fuels; and
- the available research results on long-term demand elasticities for transport fuels.

The primary focus of this study is on the current major transport fuels — automotive gasoline (leaded and unleaded), gasoil (especially automotive diesel oil), fuel oil, and aviation turbine fuel — which in 1988–89 accounted for 93.0 per cent of Australia's energy consumption in the transport sector (ABARE 1989). Some consideration is also given to alternative fuels which could come on stream in the next thirty years, although no assumptions are made about the economic or energy benefits of alternative fuels.

Although our primary focus is on energy demand forecasts produced by existing econometric and growth-based models, the limited nature of the models requires that some recognition should be given to a wider range of possible long-term transport strategies which could have significant impacts on greenhouse gas emission reductions. The potential options include switching to cleaner fuels, reducing total travel, improved fuel efficiency of automobiles and trucks, and switching to more fuel efficient modes. National forecasts of future energy demand depend largely upon projecting present trends into the future, rather than upon an understanding of how changes in the locations and behaviour of individuals and businesses affect the mode, the number, and the lengths of trips demanded.

Fuel demand forecasts are undertaken by a number of organisations. Available forecasts currently are made up to the financial year 1999–2000. The major players are the Australian Bureau of Agriculture and Resource Economics, the larger oil companies (notably BP and Shell), the National Institute of Economic and Industry Research and a few of the State energy agencies. The methods used to forecast fuel consumption vary from:

- the extrapolation of trends, based essentially on visual extrapolation;
- simple growth models which assume a relationship between the growth in fuel demand and the growth in population and gross domestic product; and
- the econometric demand model (the predictive model approach) which projects into the future on the basis of exogenous forecasts of a set of explanatory variables which have been found from historical data to be significant influences on energy demand.

The latter approach is critically dependent on the reliability of exogenous forecasts of items such as the growth in real gross domestic product, vehicle-kilometres travelled (VKT), passenger-kilometres and load factors (for air travel), fleet fuel efficiency (automobiles, trucks, aircraft), and population growth.

Fuel efficiency is itself strongly influenced by projections of vehicle technology, especially in relation to weight and carrying capacity.

There is virtually no emphasis given to a knowledge of, or use of, fuel-price elasticities of energy demand in the transport sector. The econometric procedures adopted for the main fuel types within the road transport and aviation sectors involve a set of equations relating the main underlying behavioral dimensions of the decisions of fuel consumers to a set of exogenous influences, and use the outputs of these equations in an identity to calculate levels of fuel consumption.

Forecasts of each fuel type are undertaken within each of the main sectors: road transport, railways, coastal bunkers, international bunkers, and aviation. Formal econometric modelling is restricted to automotive gasoline and automotive diesel oil in the road transport sector, and aviation turbine fuel in the domestic and international air travel markets. In 1988–89 the road transport sector plus the use of aviation turbine fuel in the air sector, represented 88 per cent of the transport sector's energy demand (ABARE 1989). Rail and sea sectoral forecasts and aviation gas (avgas) forecasts are essentially extrapolations based on data supplied from oil companies and other industry sources, tempered with judgments concerning factors believed to be influential determinants of demand.

This report is organised into a number of sections:

- issues associated with fuel conservation in the transport sector;
- documentation of available energy forecasts in the transport sector by fuel type, source of forecasts, and methods used;
- a review of alternative forecasts, with particular attention to the underlying assumptions made in the development of these forecasts;
- a review of the evidence of long-term fuel-price elasticities of demand, and any explicit or implied correspondence with the bases for Australian energy forecasts;
- an analysis of the robustness of forecasts and procedures to accommodate non-marginal changes in fuel prices, both absolute and relative, with recommendations as to future actions;
- the appendixes give more information regarding emerging aircraft technology, automobile demand models, the methodology used to derive generalised price elasticities of demand, a summary of alternative elasticity estimates, and details on the Australian aircraft fleet.

CHAPTER 2 FUEL CONSERVATION: SOME ISSUES

If governments decide to pursue energy conservation policies in the transport sector, whether to limit greenhouse gas emissions or for other reasons, what role might fuel prices play?

Evidence from the 1980s, after the petroleum crisis of 1979, on society's ability and willingness to conserve energy, supports the view that technological modification is a more successful route to fuel conservation than modification of user behaviour and attitudes (Greene 1989a, 1989b). However, there is still much that can be done by the use of imaginative vehicle use reduction measures to encourage transport users to be more efficient consumers of transport fuels.

The three major things we can do in transportation to conserve energy and reduce emissions are:

- improve vehicle efficiency;
- use alternative fuels, more generally non-fossil fuels and biomass fuels; and
- implement vehicle use reduction measures including phased-in fuel taxes and land development taxes.

If we are concerned to slow down transport energy consumption and emissions growth, it is not enough to hold the line of current fossil fuel technology. We acknowledge, however, that there are a lot of unknowns in establishing the economics of alternative fuels (with the exception of LPG). There is clearly a need to consider vehicle use reduction strategies.

Measures directed at influencing urban travel modal choice in itself, in order to encourage switching to public transport without changing demand for travel, have a very small effect, of the order of 5 per cent. The big reducers of energy consumption are efficiency improvements, non-fossil alternative fuels, and vehicle use reduction measures.

IMPROVED VEHICLE EFFICIENCY

For technical efficiency, the debate on the extent of gain in emission reduction achievable by a whole host of proposed (as distinct from proven) technical measures is quite unsettled, almost by a factor of two. This applies not only to individual technologies (for example, enleanment, temperature regulation, timing, catalysis, air pumping in road vehicles) but also to how these are aggregated given the large amount of overlap in the efficiency benefits.

The range of future technological options is extensive: variable geometric valves, reduced engine displacement, electronic controls, ultra-lean burn, stratified charge engines, ceramic components, continuously variable transmission, advanced light materials, high efficiency accessories, lighter and stronger catalysts, water and/or oxygen enriched air for diesel vehicles, increased compression ratios for oxygenates, catalytic ignition, and alternative fuels including multi-fuels.

The current set of emission controls, which have a net positive effect for light duty vehicles, are enleanment and timing (although the latter can be negative in impact if not regularly checked). Air pumping has a negative effect (Saricks 1990). For heavy duty vehicles, exhaust sensors and new fuels give positive net emission benefits.

The story is somewhat different for aircraft technology, where the potential gains in fuel efficiency (measured in terms of seat-kilometres per 100 litres of fuel) are as high as 30 per cent from the replacement of the 1990s generation of aircraft. Much of this gain is likely to be achieved by the conversion to prop fan (unducted) engines, combined with engine thermodynamics and weight reduction materials (Greene 1989a).

We need to know the conditions under which individuals and firms will purchase more efficient road vehicles. Are fuel taxes more effective than purchase price substitutes, or alternative corporate average fuel efficiency (CAFE) rules in respect of sales mixes, vehicle weights and so on?

Recent research by Greene (1989b) in studying the effect of US federal fuel economy regulations and gasoline prices on new car fuel efficiency (1978–1989) found that the CAFE standards were a significant constraint for many manufacturers, and they were perhaps twice as important an influence as automotive gasoline prices.

ALTERNATIVE FUELS

For alternative-fuelled vehicles, we need to continue to study implementation. How are we going to begin to introduce alternative-fuelled vehicles? Should they be single alternative-fuelled vehicles or dual-fuelled vehicles right at the start? If dual-fuelled vehicles are introduced, how do we encourage individuals to purchase these vehicles? Do we subsidise consumers or do we set mandates for manufacturers to sell a certain number of such vehicles? If a mandate is imposed, how do we get people to buy the fuel?

It is not enough to introduce the dual-fuelled vehicle (DFV) without some incentive for the alternative fuel to be preferred over the conventional fuel in most use circumstances. Research on understanding consumer reaction to, and acceptance of, new technologies is generally lacking. The issue of adaptation and ways of slowly changing individual fuel use without noticeably affecting lifestyle and budget is critical to the success of strategies to reduce transport emissions.

The recent development of flexible-fuel vehicle (FFV) technology for methanol–gasoline blends makes multi-fuel technology a reality not just a possibility. Unlike dual-fuelled gasoline/compressed natural gas technology, which has been available for some time in a number of countries, the FFV technology has the potential to be relatively inexpensive and nearly invisible to the consumer.

This invisibility is a critical consideration in the marketing of, and adaptation to, substitute fuels or fuel mixes. If this is combined with the intense interest in using alcohol fuels, compressed natural gas, or electricity to reduce motor vehicle emissions (Alson, Adler and Baines 1988), the emergence of significant fuel markets in the next decade or so becomes a real possibility.

Flexible- or dual-fuel markets will differ in important ways from current motor fuel markets. Whether the fuel is methanol or compressed natural gas or something else, it is likely to be derived from a different feedstock. The fuels motorists choose today are predominantly derived from petroleum, giving fuel producers considerable flexibility to adjust to changes in the market, using the same stock of refinery equipment.

Methanol in particular will require a totally different production plant. Significant swings in the methanol market share will put the entire capital stock at risk. Wide swings in demand are possible, because FFVs could perform nearly equally well on either fuel. Given the number of FFVs sold, one can estimate potential demand, but actual sales will depend on prices and consumer perceptions. Because of this, it is highly likely that alternative fuels markets created to reduce pollution will require regulation to ensure effectiveness.

This issue requires careful consideration, especially by those supporters of the role of market prices (modified by tax strategies), since many believe that the price mechanism will become an imperfect basis for encouraging both the supply and demand for alternative, more fuel efficient and cleaner transport fuels.

The idea of electrification of major roads (Nesbitt 1989) can be considered part of an FFV strategy, where infrastructure is used to assist in the reduction of transport emissions. If the limited range battery technology could be supplemented with electricity supplied through the roadway, using known technology on air gaps between the roadway and the vehicle, the idea of electric highways could be commonplace in the next century.

VEHICLE USE REDUCTION

The long run involves investigation of strategies which may not pay off for ten, twenty or fifty years, but could pay off in the time scale of the major changes in transport emission effects. It includes greater vehicle fuel efficiency and the introduction of alternative fuels as major transport fuels, changes in land use patterns, and other spatial considerations that impact on vehicle use. Many of the factors which generate vehicle use are structural, related to infrastructure which takes a long time to turn over.

OVERVIEW

It is necessary to keep an open mind on all the dimensions. What happens if governments gradually phase in an increase in fuel tax, increase charges for parking in the central business district, promote increased use of public transport, promote alternative transport fuels, subsidise certain kinds of vehicles, introduce telecommuting and so on?

In Australia, public transport fares have increased in real terms more than the price of petrol; and indeed most public transport agencies appear little interested in transport emissions — they do not see the potential role they might play in the long term, despite the current evidence that price is not a direct determinant of mode choice for urban commuting.

Allowance for all these contributing policies is a complicated modelling exercise, but it is likely to be the reality, and if we are to get a real understanding of what may be possible, it is necessary to look at all these things together. For example, the long-term growth in GNP could go down by 1 percentage point primarily because of increased expenditure on energy.

Existing econometric models do not allow for dramatic changes in vehicle efficiency or the introduction of alternative fuels. While the models can handle increases in the price of fossil fuels, if there is a cap beyond which alternative fuels would be introduced, the models cannot assess the implications of this on emissions and GNP losses.

This brief position statement highlights the importance of forecasts of types of influences on energy consumption: vehicle fuel efficiency, vehicle use and the timing of the introduction of alternative technologies. In evaluating currently available energy forecasts in Australia, these dimensions will be given consideration.

CHAPTER 3 AUSTRALIAN ENERGY FORECASTS IN THE TRANSPORT SECTOR

Three major sets of forecasts of transport fuels are currently available in Australia. These forecasts are developed by the Australian Bureau of Agriculture and Resource Economics (ABARE), the oil companies as synthesised by the Australian Institute of Petroleum (AIP), and the National Institute of Economic and Industry Research (NIEIR). ABARE has taken over from the Department of Primary Industries and Energy in the development of the Federal Government's forecasts. The three sets of forecasts up to the year 2000, completed in 1989, are summarised in table 3.1, for selected years.

The gaps in table 3.1 indicate that the available data cannot be used to allocate fuel types to particular transport sections. AIP and NIEIR supply petroleum fuel results for the entire set of users of petroleum, and only separate out road transport and aviation. The transport sector represents approximately 70 per cent of the total consumption, making it impossible to isolate rail and sea from the remaining petroleum forecasts given by NIEIR.

Where comparisons can be made, it is notable that ABARE forecasts are either virtually the same as AIP and NIEIR or slightly higher. In aggregate the NIEIR projection is around 0.5 percentage points below the ABARE projection, representing a difference of around 5000 megalitres by the year 2000. A summary of key assumed or implied forecasts of growth in respect of a number of important inputs or outputs is given in table 3.2. In the context of automotive diesel oil, there is quite a substantial discrepancy between ABARE and NIEIR.

The most problematic comparison for the fuels with a high level of consumption in the transport sector is automotive diesel oil (alternatively referred to as distillate and automotive diesel fuel). Automotive diesel oil (ADO) is a subset of the generic category of gasoil, which comprises products used in cars and trucks — commonly called ADO, products used in vehicles in off-road situations (for example, tractors, harvesters and trucks on mine sites), and products used in stationary applications (for example, boilers for electricity generation and other stationary engines). The AIP industry projections for automotive diesel fuel inland is a projection for gasoil inland, that is, total gasoil less that used by bunkers. The ABARE definition of transport fuels excludes diesel consumed by vehicles on mining sites and farms (concentrating on the Australian Bureau of Statistics

TABLE 3.1 TRANSPORT FUEL FORECASTS: AIP, NIEIR AND ABARE: MAJOR FUELS
(megalitres)

	1988–89			*1993–94*			*1999–2000*		
Item	*ABARE*	*AIP*	*NIEIR*	*ABARE*	*AIP*	*NIEIR*	*ABARE*	*AIP*	*NIEIR*
Road transport									
ADO	5085	na	5045	6777	na	5996	9196	na	7547
Automotive gasoline									
Leaded	13 500	12 872	na	7 728	7 680	na	2 357	2 788	na
Unleaded	3 429	4 308	na	10 883	10 611	na	17 439	16 577	na
Total gasoline	16 929	17 180	17 078	18 611	18 291	18 317	19 796	19 365	19 616
Railway transport									
ADO	637	na	na	671	na	na	709	na	na
IDF	66	na	na	66	na	na	66	na	na
All rail petroleum fuels	703	na	761	737	na	750	775	na	727
International bunkers									
ADO	80	na	na	73	na	na	80	na	na
IDF	71	na	na	71	na	na	71	na	na
Fuel oil	564	na	na	490	na	na	510	na	na
Coastal bunkers									
ADO	101	na	na	106	na	na	117	na	na
IDF	38	na	na	33	na	na	30	na	na
Fuel oil	564	na	na	612	na	na	666	na	na
Air transport									
Aviation gasoline	118	121	119	127	129	127	136	134	141
Aviation turbine fuel	2 970	3 031	2 980	3 609	3 826	3 280	4 578	4 496	4 015
Other groupings									
ADO in total	5 903	na	na	7 554	na	na	10 102	na	na
IDF in total	175	na	na	170	na	na	167	na	na
ADO road plus rail	5 722	9 667[a]	na	7 448	11 525[a]	na	9 905	13 609[a]	na
All shipping fuels	1 410	na	300	1 385	na	361	1 474	na	409

a. Includes non-transport stationary engines.
ADO Automotive diesel oil.
IDF Industrial diesel fuel.
na Not available.

Note ABARE publishes forecasts in petajoules and the other forecasts are published in megalitres. The conversions factors from petajoules to megalitres are: automotive gasoline 0.0342 PJ/ML; automotive diesel oil 0.0836 PJ/ML; industrial diesel fuel 0.0396 PJ/ML; aviation turbine fuel 0.0368 PJ/ML; aviation gasoline 0.033 PJ/ML; LPG 0.0257 PJ/ML; fuel oil 0.0392 PJ/ML (ABARE 1989, table 4.2, p. 46).

Sources ABARE (1989); Australian Institute of Petroleum (1989); NIEIR (1989).

TABLE 3.2 COMPARISON OF AVERAGE ANNUAL GROWTH RATES AND SHARES ASSOCIATED WITH THE ABARE AND NIEIR FORECASTS

(per cent)

Item	*ABARE*	*NIEIR*
Road transport		
Passenger vehicle stock	0.87	–
Light commercial stock	–0.4	–
Passenger and light commercial stock	–	2.4
Rigid truck stock	1.43	2.8
Articulated truck stock	2.63	2.08
Passenger vehicle VKT	3.73	–
Light commercial VKT	0.02	–
Passenger and light commercial VKT	–	0.05
Rigid truck VKT	5.3	1.39
Articulated truck VKT	4.92	1.84
Total energy consumption	2.7	1.97
Total petrol consumption	1.49	1.27
Total diesel consumption	5.74	3.73
Total LPG consumption	5.31	3.10
LPG's share 1988–2000	2.2 to 2.7	2.7 to 3.3
Automotive gasoline consumption	1.4	1.27
Automotive diesel oil consumption	5.5	3.7
Fuel efficiency		
Passenger and light commercial	–0.6 to –1.4	–1 to –1.25
Rigid trucks	–0.5 to –1.0	–1.2
Articulated trucks	–0.5 to –1.0	–0.5
Aviation transport		
Total energy consumption	3.9	2.80
Aviation turbine fuel domestic	4.8	2.47
Aviation turbine fuel international	3.1	3.30
Aviation gasoline fuel domestic	0.3	1.57
International passengers	5.9	5.09
International passenger-kilometres	–	2.48
International passenger arrivals	–	5.09
Freight tonne-kilometres	–	2.47
Other growth rates		
Gross domestic product	3.0	3.02
Population		1.3
Deregulation of airlines: costs	–	–10.0
Oil prices (1988 US$) in 1988	13.83	18.0
Oil prices (1988 US$) in 2000	18.0	25.0

– Item not forecast.
VKT Vehicle-kilometres travelled.

Note All data refer to the period 1989–2000 unless stated otherwise, and are associated with the 1989 forecasts of ABARE and NIEIR.

Sources ABARE (1989); NIEIR (1989).

definition of road transport which is in terms of travel between two places). Thus, even if we could separate stationary consumption of ADO out of the AIP figures, there is still the definitional problem of on-site vehicle use.

Advice from Shell Australia (Anne Parsons, pers. comm., 9 February 1990) suggests that it is not possible to accurately separate out the road transport and stationary consumption of ADO from the oil companies records. A substantial amount of the 9667 megalitres ADO road plus rail used in 1988–89 (NIEIR figure in table 3.1), is actually for non-transport stationary engines, and hence we have to treat the AIP historical data and projections with great caution. The ABARE breakdown (identified from tables G1 and G2 of ABARE 1989) is not very useful when we are trying to compare alternative sources of historical and forecast data.

When we compare the combined ADO forecast of AIP with the ABARE forecast in table 3.1, the differences are substantial. The comparison unfortunately has to be highly qualified because of the definitional differences: if we compared the total of ADO (that is, all sources) reported by ABARE (ABARE 1989), the differences are far less substantial. NIEIR forecasts a 3.7 per cent average annual growth rate over the 1989 to 2000 period, compared to 5.5 per cent by ABARE.

The higher projections of ABARE (or lower estimates of NIEIR) are not easy to reconcile. It does appear that ABARE's assumption on substitution for automotive gasoline and the expected growth in the road freight industry contribute to explaining the differences. More notably, however, ABARE forecasts a similar rate of growth of truck stock, but its projected rate of growth of vehicle-kilometres travelled (VKT) is substantially higher than the NIEIR rates (table 3.2). This is one plausible explanation and suggests that much more research is required into VKT growth.

Caddy (1985) shows that the main short-run impact of motor gasoline price movement on demand is felt through changes in VKT (a VKT elasticity of –0.34); in the longer run the movement towards more fuel efficient vehicles pushes the elasticity up to –0.44. An unpublished investigation by Hensher, in the context of passenger vehicles, suggests that tying VKT growth to GDP is a dangerous practice, and may partly contribute to explaining why ABARE has estimates that are generally too high.

Both the ABARE and NIEIR forecasts use reasonable assumptions of changes in fleet fuel efficiency (table 3.3). NIEIR assumes an annual average improvement of fleet fuel efficiency for all rigid diesel vehicles of 1.2 per cent , and 0.5 per cent for articulated diesel vechicles up to 2000. ABARE assumes a fleet fuel efficiency improvement averaging 0.4 per cent per year up to 2000. Thus ABARE is much more conservative on improvements in fleet average fuel efficiency, further adding to its higher ADO forecast.

We have to recognise that, where the Australian Bureau of Statistics *Survey of Motor Vehicle Use* is used to obtain fuel efficiency, there is a large margin for

TABLE 3.3 ROAD TRANSPORT FLEET FUEL EFFICIENCIES
(litres per 100 kilometres)

	1985		*2000*	
	ABARE	*NIEIR*	*ABARE*	*NIEIR*
Cars, wagons				
Petrol	12.11	–	10.25	–
Diesel	10.14	–	9.55	–
Light commercial				
Petrol	13.49	–	10.68	–
Diesel	12.19	–	11.54	–
Cars, wagons, light commercial				
Petrol and diesel	–	12.32	–	10.02
Rigid trucks				
All fuels	25.61	–	20.44	
Diesel	25.77	–	21.27	–
Articulated trucks				
All fuels	53.56	–	48.24	
Diesel	53.11	–	49.31	–

– Item not forecast.

Source ABARE (1989); NIEIR (1989).

error. Respondents are asked to directly indicate the litres per 100 kilometres achieved by their vehicles, with no allowance for different driving cycles or quality of driving and maintenance. This is unfortunately a common problem with most data sets used to obtain fuel efficiency estimates for the entire fleet of new and used vehicles (Hensher, Milthorpe, Smith & Bodkin 1986).

For vehicle registrations in the year 2000, ABARE forecasts rigid diesel truck stock to be 455 000, whereas NIEIR forecasts 431 650. (The respective numbers for articulated trucks are 60 000 and 64 000.) The numbers for diesel automobiles are very similar (ABARE 376 639; NIEIR 373 580). Thus we have a 2.6 per cent higher level of diesel road vehicles in the ABARE forecasts, reflecting the more optimistic growth in fuel substitution than NIEIR. Combined with the slower rate of fuel efficiency improvement, this can explain quite a lot, but certainly not all, of the difference in the forecast for the year 2000 of the ABARE forecast (9196 megalitres) versus the NIEIR forecast (7547 megalitres).

CHAPTER 4 THE ABARE FORECASTS

In order to appreciate the difficulties of forecasting fuel consumption in the transport sector, the Transport Research Centre undertook a comparison of ABARE forecasts (ABARE 1989) with those undertaken in 1984 by the Department of Resources and Energy (1984). The forecasts and some actual levels of consumption are given in table 4.1.

COMPARISON OF THE 1984 AND 1989 FORECASTS

There are some notable differences in the forecasts made in 1984 and 1989. Some of the comparisons are between actual demand (that is, the levels up to 1988–89 estimated in 1989) and forecasts (that is, the projections up to 1988–89 made in 1984).

A close inspection of the results suggests that, for the major fuels in road transport and aviation, beyond two years there has been a tendency to underpredict quite substantially, although for automotive diesel oil there is a substantial underprediction even after one year.

This limited comparison also adds credence to the widely held view that forecasting beyond 18 months is extremely difficult and, in particular that if econometric models are used, they should be consciously combined with a substantial amount of judgment, scenario analysis and market segmentation.

The ABARE projections made in 1989 are obtained from econometric models and extrapolative techniques. The road transport fuels and aviation turbine fuel projections are derived from econometric models; the water and rail transport fuels and aviation gasoline are projected from simple models and extrapolative techniques.

Road transport

Looking at road transport energy consumption as a whole, it is assumed by ABARE to increase at an annual average rate of 2.7 per cent from 1988–89 to 1999–2000. This is considerably higher than the NIEIR average rate of 1.97 per cent. All consumption of fuels in on-road vehicles is allocated by ABARE to the road transport sector rather than allocated between personal transport and individual industries.

TABLE 4.1 COMPARISON OF FORECASTS MADE IN 1984 AND 1989 AND ACTUAL CONSUMPTION 1985–86 AND 1988–89

(petajoules)

Item	*1985–86*	*1986–87*	*1987–88*	*1988–89*	*1989–90*	*1990–91*	*1993–94*	*1996–97*	*1999–2000*
Road transport									
Liquid petroleum gas	12.9	14.2	15.6	16.8	18.0	19.1	22.1		
	12.3	13.7	15.3	17.3	18.7	20.0	23.6	26.3	28.6
Difference (per cent)	–4.7	–3.5	–1.9	+3.0	+3.9	+4.7	+6.8		
Auto gas (unleaded)	17.2	51.3	84.7	126.6	166.6	204.1	300.5		
	18.4	47.8	82.3	120.7	178.5	227.9	372.2	503.8	596.4
Difference (per cent)	+7.0	–6.8	–3.0	–4.7	+7.1	+11.7	+23.9		
Auto gas (leaded)	526.0	491.7	456.0	409.7	364.3	321.0	206.3		
	527.6	497.8	482.6	461.7	414.8	378.3	264.3	155.5	80.6
Difference (per cent)	+0.3	+1.2	+5.8	+9.9	+13.9	+17.9	+28.1		
Auto gas (leaded plus unleaded)	543.2	539.5	540.7	536.3	530.9	525.1	506.8		
	546.0	545.6	564.9	582.4	593.3	606.2	636.5	659.3	677.0
Difference (per cent)	+0.5	+0.2	+4.5	+8.6	+11.8	+15.5	+25.6		
Automotive diesel oil	143.3	152.9	163.3	173.0	183.4	194.2	229.2		
	161.0	169.1	180.7	196.3	209.6	222.6	261.6	305.1	355.0
Difference (per cent)	+12.4	+9.9	+10.7	+13.5	+14.3	+14.6	+14.1		
Railway transport									
Automotive diesel oil	28.6	28.4	27.1	26.0	26.5	26.9	28.3		
	24.7	25.8	25.1	24.6	25.1	25.1	25.9	26.7	27.4
Difference (per cent)	–13.6	–9.4	–7.4	–4.0	–5.3	–6.7	–8.5		
Industrial diesel fuel	nf	nf	nf	nf	nf	nf	nf		
	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6

TABLE 4.1 (Cont.) COMPARISON OF FORECASTS MADE IN 1984 AND 1989 AND ACTUAL CONSUMPTION 1985–86 AND 1988–89

(petajoules)

Item	*1985–86*	*1986–87*	*1987–88*	*1988–89*	*1989–90*	*1990–91*	*1993–94*	*1996–97*	*1999–2000*
Electricity	3.5	3.8	4.4	4.9	5.0	5.1	5.5		
	3.8	4.0	4.5	5.2	5.4	5.5	6.1	6.5	6.9
Difference (per cent)	+8.6	+5.3	+2.3	+34.7	+8.0	+7.8	+10.9		
International bunkers									
Automotive diesel oil	0.8	0.9	0.9	0.9	0.9	0.9	0.9		
	0.9	1.4	2.7	3.1	2.7	2.7	2.8	3.0	3.1
Difference (per cent)	+12.5	+55.5	+200.0	+244.0	+200.0	+200.0	+153.0		
Industrial diesel fuel	3.1	2.8	2.5	2.3	2.0	1.8	1.3		
	3.0	3.2	3.2	2.8	2.8	2.8	2.8	2.8	2.8
Difference (per cent)	–3.2	+20.0	+28.0	+21.7	+40.0	+55.5	+115.0		
Fuel oil	29.0	29.3	29.5	29.8	30.0	30.2	30.6		
	16.6	17.2	18.7	22.1	18.7	18.8	19.2	19.6	20.0
Difference (per cent)	–42.7	–41.3	–36.6	–25.8	–37.7	–37.7	–37.3		
Coastal bunkers									
Black coal	4.1	4.1	4.1	4.1	4.1	4.1	4.1		
	3.3	3.8	3.1	3.6	3.5	3.7	4.1	4.3	4.3
Difference (per cent)	–17.1	–7.3	–24.4	–12.2	–14.6	–9.7	0.0		
Automotive diesel oil	4.4	4.4	4.4	4.4	4.4	4.4	4.5		
	3.3	5.6	4.3	3.9	3.9	4.0	4.1	4.3	4.5
Difference (per cent)	–25.0	+27.2	–2.3	–11.4	–11.4	–9.1	–8.9		
Industrial diesel fuel	2.7	2.4	2.2	1.9	1.7	1.6	1.1		
	2.7	2.3	1.8	1.5	1.5	1.4	1.3	1.3	1.2
Difference (per cent)	0.0	–4.2	–18.2	–21.0	–11.8	–12.5	+18.2		

TABLE 4.1 (Cont.) COMPARISON OF FORECASTS MADE IN 1984 AND 1989 AND ACTUAL CONSUMPTION 1985–86 AND 1988–89

(petajoules)

Item	*1985–86*	*1986–87*	*1987–88*	*1988–89*	*1989–90*	*1990–91*	*1993–94*	*1996–97*	*1999–2000*
Fuel oil	29.9	30.2	30.5	30.7	31.0	31.2	31.7		
	24.8	24.2	24.6	22.1	22.8	23.1	24.0	25.0	26.1
Difference (per cent)	–17.1	–19.9	–19.3	–28.0	–26.5	–25.9	–24.3		
Natural gas	nf	nf	nf	nf	nf	nf	nf		
	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Air transport									
Aviation gasoline	3.6	3.7	3.7	3.7	3.7	3.7	3.8		
	3.5	3.7	3.9	3.9	4.0	4.0	4.2	4.3	4.5
Difference (per cent)	–2.8	0.0	+5.4	+5.4	+8.1	+8.1	+10.5		
Aviation turbine fuel	85.7	88.5	91.5	94.6	97.8	101.3	117.0		
	89.3	93.2	102.5	109.3	113.4	118.0	132.8	149.5	168.5
Difference (per cent)	+4.2	+5.3	+12.0	+15.5	+16.8	+16.5	+13.5		

nf Not forecast.
Autogas Automotive gasoline.

Notes 1. First row is forecasts made in 1984. Second row is actual levels up to 1988–89; after 1988–89 is forecasts made in early 1989. Third row is percentage difference between forecasts made in 1984 and 1989 recognising that the 1989 data include actual consumption up to 1987–88.
2. A positive sign indicates either that the 1984 forecasts were low in comparison to historical data in the period 1985–96 to 1987–88, or that the forecasts for the period 1988–89 to 1999–2000 were revised upwards in the 1989 edition.

Source ABARE (1989); Department of Resources and Energy (1984).

The assumed growth in ADO is the most rapid (5.5 per cent compared to 3.7 per cent of NIEIR) due to the assumed continued substitution for automotive gasoline in the commercial vehicle sector and the continued growth of the road freight industry. We note the recent efforts by State governments, especially New South Wales, to assist the railways to make them more competitive with road freight vehicles.

Automotive gasoline consumption is assumed by ABARE to increase at 1.4 per cent per year, the same as the average rate observed since the mid 1970s. The mix of leaded and unleaded petrol is assumed to go from 80:20 to 12:88 by 1999–2000.

Aviation

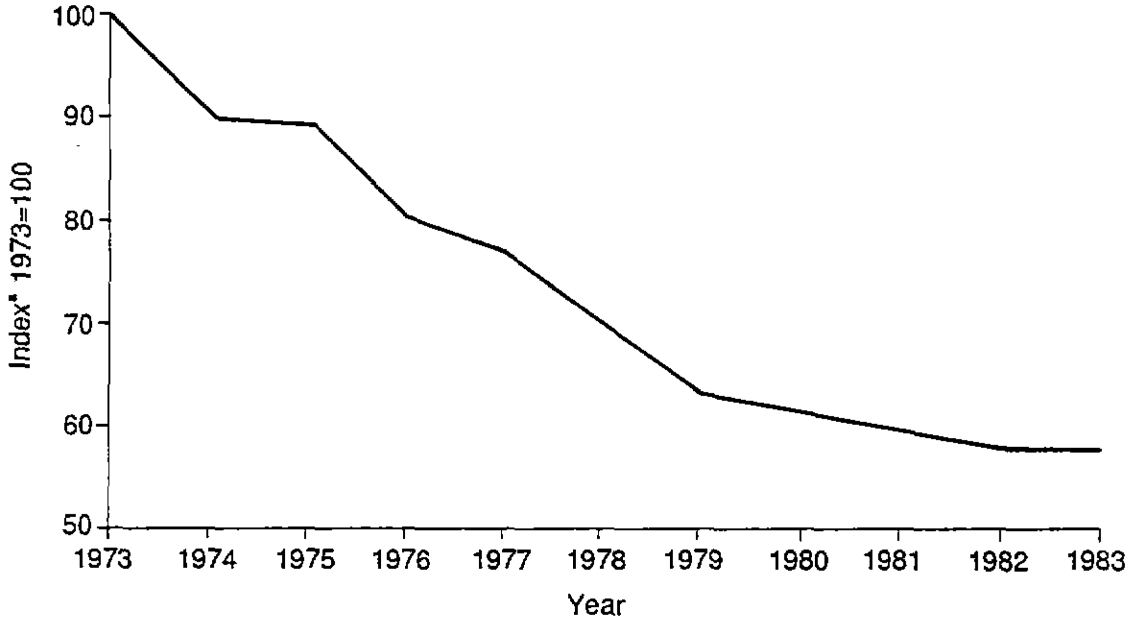
The air transport sector's major fuels are aviation turbine fuel and aviation gasoline. The projections have been revised upwards substantially since the *Energy 2000* report (DPIE 1988), increasing from 2.9 per cent to 3.9 per cent per year. This revision is due to the downward revision in expectations concerning future oil prices and the substantial upward revision in the Department of Transport and Communications' forecasts of growth in international passengers to and from Australia (5.9 per cent per year). *Energy 2000* assumed 2.6 per cent per year up to the year 2000.

The revised 3.9 per cent contrasts with the worldwide best estimate of air passenger growth averaging 5.7 per cent annually for the next 15 years (Boeing 1989; McDonnell Douglas 1989). Discussions with the Domestic Aviation Division of the Department of Transport and Communications (6 February 1990) suggest that according to the long-term trends the growth of domestic passengers is close to 7 to 8 per cent, implying that the ABARE revision used in the 1989 energy forecasts is also too low. This further helps to isolate the sources of forecast error. However, with deregulation any assumptions on domestic aviation could be proved to be substantially incorrect over the next few years.

Beyond the year 2000 further consideration will have to be given to the fuel efficiency of the 1990s generation of aircraft, which may come on stream earlier than currently envisaged once the skies are opened to new and diversified competition. A synthesis of new aircraft technology, together with the estimated effectiveness of advanced energy efficiency technology for aircraft, is given in appendix I. All current forecasts assume the existing composition of the aviation fleet. Improvements in the energy intensity of aviation have also been notable since the early seventies (figure 4.1, International Energy Agency 1987).

Shipping

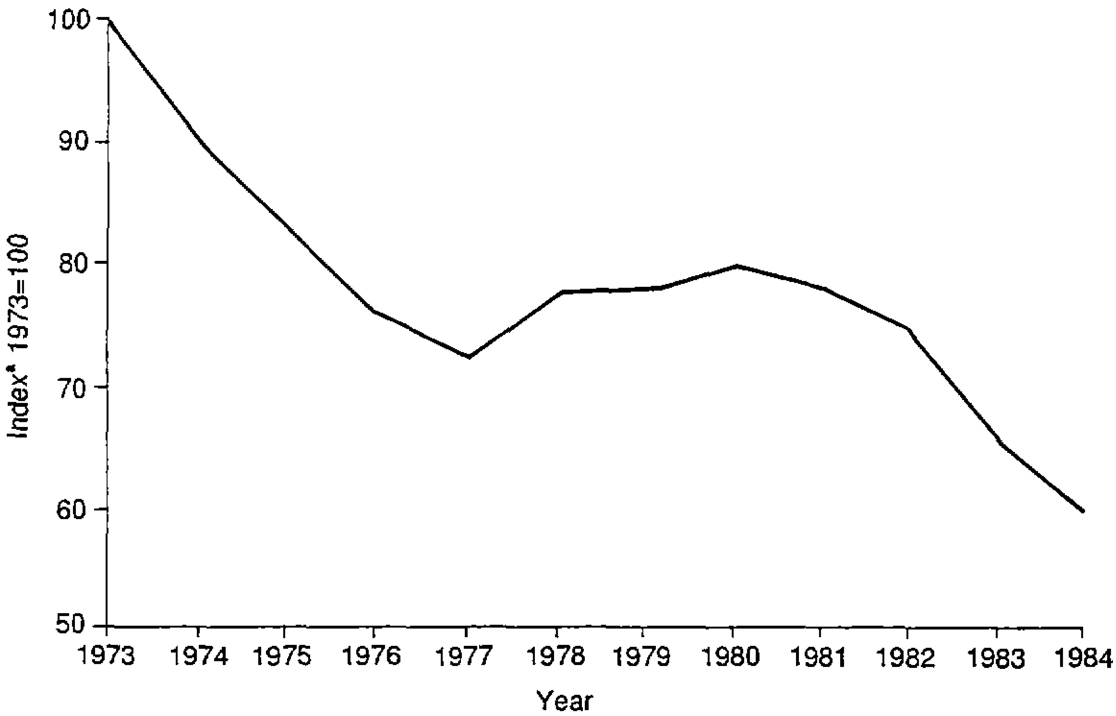
For the sea vessels, the oil companies supply historical data on a State-by-State and fuel-by-fuel basis. ABARE uses essentially visual extrapolation. Given the relatively small amount of local fuel going into ships' bunkers, we do not comment



a. Index based on consumption of aviation fuel in OECD countries divided by world total of ton-kilometres flown.

Source International Energy Agency (1987).

Figure 4.1 Energy Intensity in Aviation



a. Index based on world bunker oil demand divided by laden ton-miles.

Source International Energy Agency (1987).

Figure 4.2 Energy Intensity in World Shipping

on this sector. A substantial quantity of fuel is purchased overseas (although the amount is unknown).

The greatest potential for reducing greenhouse gas emissions from international bunker fuels comes from improved technical efficiency, by improving revs per minute as well as the surface area of vessels which creates the resistance. A gradual shift from steam turbine ships to motor diesel powered ships, improvements in the design of diesel engines and propellers, and slow steaming have all added to the improved energy efficiency of the maritime sector, as measured by world bunker oil demand per laden ton-mile (figure 4.2, International Energy Agency 1987).

Coastal bunkers are further limited technologically by port constraints, which condition the size, draft, beam, and length of vessels. The economic life of a ship is typically 10 to 15 years, although many have older design lives of up to 25 years. It is reasonable to assume that the current fleet represents the fleet up to the year 2000. However, even if there was a disagreement about this, including any claim of a major program of engine retrofit, which is extremely unlikely, any planned changes in technology and operating environment are unlikely to affect the aggregate consumption of bunker fuels.

Exogenous influences on the forecasts

In the road and aviation sectors, the major exogenous inputs are the future rate of economic growth (represented by gross domestic product), the future path of energy prices, and the technological developments in aircraft and automobile engine technology. GDP is assumed to grow at 3 per cent per year over the period up to the year 2000. A close functional dependence is assumed to exist between energy consumption and economic growth, although the relationship could be significantly affected by effective conservation measures (Marks 1989a). ABARE assumes that the prices of petroleum products in Australia will rise in real terms, in line with movements in world oil prices.

Industry analysts suggest that oil prices will remain relatively low in real terms throughout the 1990s (Clarke 1989). ABARE assumes that world oil prices are most likely to rise over the projection period to an average of US$18 per barrel in 1988 dollars in the year 2000, an increase from a world trade weighted average of US$13.83 per barrel in 1988. This increase in price per barrel is based on the assumption that OPEC will increase its share of world oil production and trade over the 1990s, but not to the extent that prices will rise steeply.

NIEIR questions the assumption of a constant US$18 per barrel price over the period to 1990. It raises doubts about the much higher 1990–2000 oil production profile of 1989 compared to the corresponding 1987 Department of Primary Industries and Energy report. That is, unless some tax reductions were implemented, funds accruing to the industry may be insufficient to attain the projected production levels.

The moderating influences on OPEC price increases are:

- the continuing tensions within OPEC, although some OPEC watchers suggest that OPEC, with about two-thirds of the world's reserves, is expected to reassert control over prices sometime in the 1990s (Transportation Research Board 1989);
- the demonstrated price-responsiveness of both world oil demand and non-OPEC supply;
- the recent significant increase in the level of demonstrated world oil reserves;
- the existence of very large quantities of alternative sources of liquid fuels such as oil shales and heavy crude oil.

ALTERNATIVE FUELS

Petroleum products are assumed by ABARE to continue to dominate transport energy use up to the year 2000. LPG, natural gas and methanol are considered to have some potential as economically viable alternative transport fuels in the 1990s.

LPG

ABARE assumed a 2.7 per cent share of total road transport fuel consumption by the year 2000, increasing from the 1988–89 share of 2.2 per cent. The rapid growth in consumption of LPG is assumed to continue to 1999–2000, but at a lower rate than in the recent past. The distribution infrastructure is now quite extensive, although further market penetration may be constrained by its availability.

Natural gas

Although natural gas is currently a negligible contributor to transport energy consumption, the gas distribution infrastructure is in place, and natural gas could be promoted much more as an alternative road transport fuel. The technology in vehicles is proven overseas, and is in the demonstration phase in Australia.

The State Transit Authority of New South Wales introduced two buses powered by compressed natural gas (CNG) in the Sydney metropolitan area in May 1989, returning a 36 per cent saving in fuel costs per vehicle, at a current fuel price of $7.30 per gigajoule. Another 200 CNG powered buses are being considered, with an eventual replacement of the entire fleet of 1500 buses (*Energy Focus* 1990). The State Transit Authority claim a 25 per cent reduction in carbon dioxide emissions, a 33 per cent reduction in hydrocarbon emissions, and a 50 per cent reduction in carbon monoxide emissions. The capital and operating costs are comparable to diesel.

Market penetration for CNG would have to be preceded by the installation of compression or liquefaction facilities and the necessary modifications to vehicular fuel systems to enable transport use. Natural gas is a candidate for dual-fuelled vehicles, and with the right incentives, both in terms of vehicle purchase price and fuel prices, could be introduced fairly soon.

Despite the current efforts in Australia to promote this alternative fuel for road transport, its contribution to energy consumption in transport up to the year 2000 is assumed by ABARE to be negligible. Given the oil price outlook, the economics of natural gas are unlikely to improve markedly over the next ten years unless significant improvement in its ease of storage or use occurs. The current demonstrations are in urban transit buses and long-haul trucks. Clark (1989) cites forecasts of 4 petajoules of sales in these two areas by 1993–94.

Given the dominance of the car in the total annual vehicle-kilometres (for example, 92 per cent of total vehicle-kilometres in Sydney in 1988, with another 7 per cent for commercial vehicles), the major savings in energy consumption will flow from car conversion.

Methanol

This fuel currently has a low level of public acceptance of its potential. Although there is active development and demonstration in a number of countries (DeLuchi, Johnston & Sperling 1988), there is currently no production of this fuel in Australia for transport purposes. The share of energy derived from methanol is assumed by ABARE to be negligible in the projection period.

ABARE'S MODELS

The assumptions on growth rates are one means of projecting energy consumption, or can form the basis for projecting exogenous variables in an econometric model. To assist us in assessing the forecasts, we need to set out the models and extrapolative procedures used by ABARE for each type of fuel and transport sub-sector. The main features are summarised below.

ABARE: ROAD TRANSPORT FUEL

The ABARE forecasts made in 1989 were not based on the set of econometric models originally developed by the Department of Primary Industries and Energy (1987). Some major concerns with the forecasts derived from the suite of road transport models required ABARE to adopt a more pragmatic and judgmental strategy. However, there is a strong belief that the econometric approach is still desirable in this context and ABARE embarked on a major review and revision of the road transport model system (see ABARE 1991).

ABARE's 1989 forecasts of energy consumption were obtained from a simple identity which linked vehicle utilisation to fuel efficiency. To obtain estimates of the average rate of vehicle utilisation and fleet fuel efficiency it was necessary to identify the size and composition of the new and used vehicle fleet. Separate estimates were obtained for six categories of vehicles (passenger, light commercial, rigid trucks, articulated trucks, buses and motor cycles) and each fuel where appropriate (petrol, diesel and LPG). Somewhat informal methods were used to forecast energy consumption for the fleet of buses and motor cycles.

The demand for new vehicles was modelled as a function of income, new vehicle prices, new vehicle fuel efficiencies and lagged new vehicle registrations. For articulated trucks the fuel costs were related to an index of interstate rail freight rates, to reflect changes in the relative cost-competitiveness of road and rail transport.

The empirical models are summarised below.

New cars and station wagons (NCSW)

$$\ln NCSW_t = 8.1420 + 0.325 \ln RGDP_t / RVP_t - 0.3840 \ln RFPE1_t + 0.3341 \ln NCSW_{t-1} \qquad R^2 = 0.90$$

New light commercial vehicles (NLC)

$$\ln NLC_t = 1.5224 + 0.5318 \ln RGDP_t - 0.3591 \ln RFPE2_t + 0.4613 \ln NLC_{t-1} \qquad R^2 = 0.94$$

New rigid trucks (NRT)

$$\ln NRT_t = 0.0354 + 0.7226 \ln RGDP_t - 0.1768 \ln RDPE1_t + 0.4649 \ln NRT_{t-1} \qquad R^2 = 0.91$$

New articulated trucks (NAT)

$$\ln NAT_t = -7.5578 + 1.0174 \ln RGDP_t - 0.4799 \ln RAT_t + 0.4649 \ln NAT_{t-1} \qquad R^2 = 0.76$$

where: RGDP is the real GDP (1979–80 $ million); RVP is an index of real vehicle purchase price (1980–81 = 100); RFPE1 = RFP . VENPV/11.1; RFPE2 = RFP . VENLC/12.1; RDPE1 = RDP . VENDRT/24.9; RAT = RDP . VENAT / (51.7 . RRLRT); RFP is a real petrol price index (1980–81 = 100); RDP is a real diesel price index (1980–81 = 100); VENPV, VENLC, VENDRT, VENAT are the efficiencies (in litres per 100 kilometres) of new petrol passenger vehicles, petrol light commercial vehicles, diesel rigid trucks, and diesel articulated trucks respectively; and RRLRT is an index of real rail freight freights.

Used vehicle registrations were derived from the application of a vehicle survival function of the logistic form. The physical age of the vehicles was the prime determinant of scrappage. No allowance was made for economic deterioration. The survivability model was parameterised using vehicle registration data from the four censuses in 1976, 1979, 1982 and 1985.

Estimates of the average annual kilometres travelled by vehicles of a given age and year of first registration were derived from estimates of the average annual distance travelled by the vehicle stock, and a model of the relative utilisation of vehicles of different ages, based on a negative exponential function.

Finally the average fleet fuel efficiency was estimated for vehicles of each given age and year of first registration from the average rate of fuel consumed by new vehicles and the effects of increasing vehicle age on rates of fuel consumption. The resulting utilisation rates and fleet average fuel efficiencies were used to derive energy forecasts, after assumptions were imposed on each model in relation to the exogenous variables.

The assumptions underlying the forecasts of levels of the exogenous variables were:

- real vehicle prices for passenger cars and light commercials to decline by 1 per cent per year;
- passenger vehicle fuel efficiency to increase by 0.5 per cent per year, light commercial vehicle fuel efficiency to increase by 1.4 per cent per year up to 1993 and then increases by 0.6 per cent thereafter up to 2000, rigid and articulated truck fuel efficiencies to increase by 1 per cent per year up to 1994 and then by 0.5 per cent per year up to the year 2000;
- real rail freight rates to decline annually by 1 per cent; and
- average rate of growth in real GDP of 3 per cent per year.

There was no direct link between fuel prices and energy demand in the 1989 ABARE road transport fuel forecasts (or those of AIP and NIEIR). Given that the demand for fuel is derived from the demand for travel, it is more sensible to approach the problem from the perspective adopted by ABARE. This is also the general thrust of the more detailed modelling exercise undertaken by Hensher, Gunn and Botchie (1989) and by Hensher, Smith and Milthorpe (unpublished) for obtaining all the necessary elasticities for deriving the fuel-price elasticity of energy demand (see appendix II).

In chapter 5 we utilise a knowledge of the relationship between fuel prices, fleet size, vehicle utilisation and fuel efficiency to derive suitable fuel-price elasticities of energy demand.

Unfortunately, without re-estimating the ABARE models it is not possible to identify these three elasticities in order to derive the elasticity of current interest.

Road transport fuel: comparison with NIEIR

The NIEIR approach has many similarities to the ABARE method. Details of the equation set are not available. Apart from a number of different forecast assumptions for the exogenous variables, which are thought to be the major explanation for any differences in forecasts, the main differences are:

- vehicle maintenance costs are included in the NIEIR model for the demand for passenger vehicles;

- for rigid and articulated trucks, demand is also related to the overall activity in the goods sector; and
- NIEIR adjust the fleet fuel efficiency estimates obtained from the Australian Bureau of Statistics *Survey of Motor Vehicle Usage* (SMVU) to reconcile the SMVU results with known levels of fuel consumption, assuming that the average annual kilometres per vehicle remain at the 1988 level.

ABARE: AVIATION TRANSPORT FUEL

Separate econometric models have been developed for aviation turbine fuel consumed by domestic and international aviation. The version of each model used to derive the forecasts reported in ABARE (1989) was not then published (but see ABARE 1991). The models reported in Department of Primary Industries and Energy (1987) have been superseded.

Approximately half of the aviation turbine fuel is consumed in each of the domestic and international markets (domestic consumption was 54 per cent in 1983–84, 52 per cent in 1984–85, 47 per cent in 1985–86, 53 per cent in 1986–87, and 51 per cent in 1987–88).

Domestic aviation

The domestic aviation model was estimated on a time-series from 1969–70 to 1986–87. Three equations were separately estimated:

$$\ln \mathrm{PASKM} = -6.524 + 1.668 \ln \mathrm{RGDP}_t + 0.748 \ln \mathrm{RAWE}_t + 0.0387 \ln \mathrm{RPP}_t - 0.663 \ln \mathrm{RAF}_t \qquad R^2 = 0.99,\ DW = 1.62$$

$$\mathrm{SKM}_t = [1/u_t]\ \mathrm{PKM}^*_t$$

$$\ln \mathrm{DAC}_t = 1.6070 + 0.7524 \ln \mathrm{SKM}_t \qquad R^2 = 0.99,\ DW = 2.45$$

where, for each year t: PASKM is number of passenger-kilometres; RGDP is real GDP; RAWE is real average weekly earnings; RPP is real petrol price (to represent intermodal competition); RAF is real domestic air fares; SKM is number of seat-kilometres; u is system-wide load factor; PKM^* is predicted passenger-kilometres; and DAC is domestic aviation turbine fuel sales.

Forecast assumptions made are:

- real GDP is assumed to grow by 3 per cent per year up to 1999–2000;
- real average weekly earnings fell by 1.3 per cent in 1987–88, and are assumed to increase by 2 per cent in 1988–89, up to 1.2 per cent in 1989–90 and 1.8 per cent thereafter;
- real air fares decreased nearly 1 per cent in 1986–87, and are assumed to decrease by 0.5 per cent per year to 1989–90, then to increase by 0.5 per cent to 1999–2000;
- system-wide load factor is assumed to remain constant at the 1986–87 value of 0.73 (this may be highly inaccurate after deregulation); and

- real petrol prices fell by 3 per cent in 1987–88 and are assumed to grow by 1 per cent per year up to the end of the century.

These combined assumptions lead to an average annual growth rate of 4.8 per cent per year for the period 1988–89 to 1999–2000. This compares with the average annual growth rates of 5.7 per cent over the 10 years to 1987–88, and 5.3 per cent over the 5 years to 1987–88.

International aviation

The international demand model is less complex, and is driven by one variable: total international passengers. No allowance is made for the possibility that inbound passengers are travelling on flights which consume fuel from non-Australian sources.

$$\ln IAC_t = 5.591 + 0.540 \ln IP_t \qquad R^2 = 0.97, DW = 1.33$$

where IAC is sales of aviation turbine fuel (in kilolitres) to international operators in year *t*, and IP is number of international passengers in year *t* arriving and departing Australia.

Forecasts of international passengers are supplied by the Department of Transport and Communications. The annual growth rate of international passengers each financial year over the period 1988–89 to 1999–2000 is 5.9 per cent per year. Over the 10 years to 1987–88, the average annual growth rate was 8.4 per cent. From this base aviation turbine fuel consumption was projected to grow at an average rate of 3.1 per cent per year over the forecast period. The average growth rates over the 10 and 5 years to 1987–88 were 4.9 per cent and 8.5 per cent respectively.

The combined average growth rate of domestic and international aviation consumption of aviation turbine fuel is 4.1 per cent over the forecast period, compared to an average growth rate over the 10 and 5 years to 1987–88 of 3.9 per cent and 6.8 per cent respectively.

Aviation transport fuel: comparison with NIEIR

The NIEIR approach to forecasting aviation turbine fuel also distinguishes domestic and international airline activity. Domestic airline activity is measured by passenger-kilometres and freight tonne-kilometres. The former is assumed to be a function of the product of the number of passengers carried and distance travelled. The latter measure is derived by aggregating the products of tonnes of freight over each stage and stage length.

The explanatory variables in the passenger-kilometre model are income per capita, real gross non-farm product and real domestic airline fares. Freight tonne-kilometres is modelled as a function of domestic demand and freight rates. Passenger-kilometres travelled is then used to generate total passenger tonne-kilometres. Domestic aviation turbine fuel is predicted given total tonne-kilometres and assumptions about the average fuel efficiency of the existing fleet and average system load factor.

Aviation turbine fuel consumption by international operators is modelled by NIEIR as a function of the number of international travellers. Although this relationship is also used by ABARE, NIEIR uses total international arrivals rather than all arrivals and departures.

Aviation gasoline (avgas) demand is forecast from historical trends, allowing for the changes in the level of domestic activity. ABARE assumes that the demand for avgas will grow at an average rate of 0.3 per cent per year, based on consumption trends in all Australian States over the last 5 and 10 years up to 1987–88. The NIEIR assumes an average annual growth rate of 1.57 per cent, which is substantially higher. There is no explanation found in the NIEIR study other than a statement that avgas demand, which has varied considerably, historically is related to the level of domestic activity (NIEIR 1989, part 2, p. 2.25). This significant discrepancy is of concern, despite the minor role of avgas in the overall transport energy task.

ADDENDUM TO CHAPTER 4: THE ABARE FORECASTS

In January 1991, ABARE published new projections of energy demand and supply, which covered the period 1990–91 to 2004–05 (ABARE 1991). The previous publication had projections which extended only to 1999–2000. The new publication contained details of a revised methodology for forecasting Australian road transport fuel demand. The latest projections of energy demand revised downwards the previous ABARE estimates of future Australian road transport fuel demand. Projections of aviation fuel demand were revised upwards slightly.

Road transport energy forecasting models

Forecasts of the demand for automotive gasoline, automotive disel oil, LPG and natural gas used by the road transport sector are now based on a model documented in Donaldson, Gillan & Jones (1990). The model documented in that paper focuses on the passenger car component of the fleet but similar techniques were used for other components of the road transport market.

Passenger car transport

Basically, the new model contains only two components, the estimated size of the vehicle stock and the average quantity of fuel consumed by vehicles. The forecasts for the commercial fleet are slightly more complicated, in that there is a breakdown of the average amount of fuel consumed into the components of average rate of fuel consumption per unit of carriage and average distance travelled per type of vehicle per year.

Estimates of the size of the passenger vehicle fleet are based on a logistic function of the form:

$$S/P = a/(1 + e^{-(b + ct)})$$

where: *S/P* is registrations per adult person; *a* is the saturation level (at which the rate of growth in car ownership per person falls to zero); *b* and *c* are parameters determining the position of the growth curve along the time axis and the rate at which the growth curve approaches saturation respectively; and *t* is time.

Accordingly, car ownership per head of population is modelled simply as a function of time, subject to some saturation constraint. In this model, economic variables are omitted on the assumption that, while they will determine whether people purchase new vehicles or retain old vehicles longer, they will not affect the level of the vehicle stock. Parameterisation of this model is described in ABARE (1991).

The average fuel consumption per vehicle per year (AFC) was modelled directly as a function of national income (approximated to an index of real GDP) and the real price of gasoline. It is important to distinguish AFC from the *average rate of fuel consumption per vehicle kilometre*, as in the previous model. Changes in AFC should be understood to combine the effects of changes in kilometres driven per vehicle and changes in average fuel economy per vehicle kilometre.

The following function was used to estimate AFC, modelled on data over the period 1970–71 to 1988–89.

$$\log AFC_t = \underset{(19.63)}{9.5} - \underset{(-2.39)}{0.14} \log P_t - \underset{(-3.92)}{0.18} \log GDP_t - \underset{(-4.34)}{11.82}\, D_1 + \underset{(4.32)}{1.57}\, D_2$$

where: P_t is the index of real automotive gasoline prices in year t; GDP is the index of real GDP in year t; D_1 is a dummy variable for the first two years of the first oil price shock; and D_2 is a dummy variable for 1981–82 (when demand contracted despite falling real prices). (Figures shown in parentheses are t-statistics.)

$AFC_{2001-02}$ was estimated at 1693.7 litres per year.[1] AFC was multiplied by the forecast size of the car stock, to form an estimate of total fuel used by cars and station wagons. The total fuel figure was then divided into categories of automotive gasoline, automotive diesel oil, LPG and natural gas, on the basis of actual and expected penetration levels of these fuels. Automotive gasoline was then split between leaded and unleaded.

1. In the previous ABARE model, forecast fuel consumption for petrol passenger cars in 2000 was 10.25 litres per 100 kilometres. The revised ABARE (1991) projections do not provide explicit forecasts for average fuel economy, although a fleet average car fuel efficiency for 2004–05 of 10.9 litres per 100 kilometres is stated as 'implicit in the business-as-usual scenario' (p. 33). Taking the forecast AFC, if the average kilometres travelled per vehicle rise to 18 000 per year, then the implied average fuel economy would be 9.4 litres per 100 kilometres. At high levels of motorisation, there is, however, no clear expectation vehicle-kilometres would increase.

Commercial road transport
Fuel consumption for the commercial vehicle fleets (rigid and articulated trucks, light commercial vehicles, buses and motor cycles) was estimated on the basis of forecasts of average fuel consumption per unit of distance, the average distance travelled per year and the respective vehicle stocks for these fleets. Estimated values for these components of total fuel consumption are shown in ABARE (1991, p. 48). Fleet average fuel efficiency estimates for the commercial fleet used in the latest set of forecasts are of similar order to those listed earlier in table 3.3. Estimates of the 1999–2000 fleet average rate of fuel consumption, expressed in litres per 100 kilometres, for rigid trucks, articulated trucks and light commercial vehicles, were 21.27, 49.30 and 10.70 respectively.

Air transport
Estimates for consumption of energy in the air transport sector rely heavily on forecasts and assumptions for passenger numbers, air fares and other variables developed by the Bureau of Transport and Communications Economics.

ABARE (1991) adopts different approaches for determining projections of international and domestic aviation fuel demand.

International aviation fuel demand projections are modelled as a function of the number of international passengers forecast for any year.

Projections of domestic demand for aviation turbine fuel are modelled using three separate equations, estimated from data for the period 1969–70 to 1989–90. The first equation estimates the number of passenger-kilometres as a function of real GDP, real average weekly earnings, real petrol prices and real air fares. The estimate of passenger-kilometres is then adjusted by an estimate of the system-wide load factor for the year, to arrive at an estimate of the number of seat-kilometres. Finally, the estimate of seat-kilometres in the year is used to determine an estimate of the level of aviation turbine fuel sales for domestic aviation. Details on projected future growth rates of the independent variables and the functional form for the estimation models are shown on pages 45 and 46 of ABARE (1991).

Fuel consumption forecasts

ABARE (1991) gives fuel forecasts for 1998–99 and 2001–02, rather than for 1999–2000 as in ABARE (1989). This has placed some limitation on comparability between the two publications. These two forecasts are compared below.

The forecasts of Australian transport energy consumption have been adjusted slightly downwards for all modes, except air transport. Air transport energy consumption is now forecast to grow at an average annual rate of 5.0 per cent over the period 1988–89 to 2001–02, whereas previously it was forecast to grow at an average annual rate of only 3.9 per cent, in the period 1988–89 to 1999–2000. The same estimates of growth in energy consumption for the road transport sector energy consumption have been amended from 2.6 per cent per year to 1.8 per cent, closer to the average annual growth rate estimated by NIEIR (1989), of 1.97 per cent. The ABARE (1991) forecast of total energy consumption for transport in 2001–02 is slightly lower than the previous forecast for 1999–2000.

Forecast growth in the consumption of automotive gasoline and automotive diesel oil (ADO) have both been revised downwards from the prior projections (ABARE 1989). ADO consumption growth has been projected at an average rate of 2.5 per cent per year up to 2004–05, down from the previous estimate of average growth in ADO consumption of 5.5 per cent per year up to 1999–2000. Automotive gasoline growth is now forecast to grow at a lower average rate of 0.9 per cent per year up to 2001–02, falling slightly thereafter to an average of 0.8 per cent per year up to 2004–05.

References

ABARE 1991, *Projections of Energy Demand and Supply — Australia 1990–91 to 2004–05*, AGPS, Canberra.

Donaldson, P. K., Gillian, P. & Jones, B. P. 1990, Road transport fuel demand in Australia: Projecting vehicle fuel use, ABARE paper presented at the Conference of Economists, Economic Society of Australia, Sydney, 24–27 September.

CHAPTER 5 LONG-TERM FUEL-PRICE DEMAND ELASTICITIES: A SYNTHESIS OF THE EVIDENCE

Forecasting procedures which allow for the unit price of energy, either implicitly or explicitly, assume a relationship between changes in fuel prices and changes in the quantity of energy consumed. There is a vast and often conflicting literature on direct elasticities of fuel demand with respect to fuel prices.

In this chapter we identify the major evidence from Australian and international studies, as a way of establishing a reference point for our inquiry into the key Australian forecasts of fuel demand.

THE RELATIONSHIP BETWEEN PRICE AND DEMAND

Why is a knowledge of the elasticity of demand for energy with respect to fuel price an important item of information? It provides a means of identifying the unique contribution that fuel price has on the overall demand for energy. This answer, however, is crucially dependent on the assumption, made in deriving the elasticity estimate, that any other important influences on energy consumption have been accounted for (that is, separated out from the price effect).

The challenge in any studies designed to obtain elasticity estimates is to separate out the influences of the major behaviourial determinants of energy demand. Extrapolative methods based on simple growth assumptions and judgment typically are unable to establish the effect that fuel prices have on future demand.

Government organisations and oil suppliers are particularly interested in the influence of price, and hence need to recognise the contribution that formal methods, such as an econometric model, can make to separating out the contributing behaviourial influences. Even with the most appropriate econometric model and available data there is still a need for an input of good judgment, experience, scenarios and market segmentation which is not well handled by a mathematical model.

Because road transport and aviation are the dominating modes in transport, government departments and oil companies have concentrated on developing econometric models in these two areas, and used simple extrapolative procedures in all other areas. Econometric models have been developed to:

- forecast energy consumption directly by regressing total or per head energy consumption on a set of explanatory variables such as GDP or GDP per head and fuel prices; and
- forecast energy consumption as a by-product of separate forecasts of the major behaviourial influences on energy demand. In the context of automobile demand these behaviourial influences are vehicle ownership, vehicle use and fleet fuel efficiency, each treated as endogenous variables.

The basic approaches adopted by ABARE and NIEIR have been set out in detail in chapter 4. Energy consumption can then be derived from such models in either of two ways:

- by using the appropriate elasticities (denoted ε) derived from each model to calculate a fuel-price elasticity of demand (see appendix III for a proof):

  $$\varepsilon_{e,p} = \varepsilon_{k,p} + \varepsilon_{v,p} - \varepsilon_{f,p}$$

  where e is total or per head energy consumed, v is vehicles registered or per head, k is total kilometres per vehicle or per vehicle per head, f is average fleet fuel efficiency and p is unit fuel price[1];
- by using the models to provide forecasts of the endogenous variables which are themselves used to forecast energy consumption: total or per head energy demand equals total or per head vehicle-kilometres divided by average fleet fuel efficiency.

ROAD TRANSPORT

With the exception of the automotive gasoline fuel price elasticity determined by Caddy (1985) of –0.25, such elasticities cannot be derived from available information.

The fundamental difficulty of inferring any reliable fuel-price elasticity from the extant set of known Australian econometric models, used predominantly (almost solely) to obtain forecasts of energy consumption as distinct from identifying fuel-price and other elasticities of demand.

There is a lot more fundamental work required in Australia on both model form and data. One area where this has occurred is in automobile ownership and

1. There are a number of advantages to estimating component demand equations and not simply estimating gasoline demand directly. First and most obviously, one may be interested in how price and income affect gasoline consumption and not simply in the magnitude of the effect. The distributional or other consequences of improved fuel efficiency versus, say, reduced automobile ownership might be of interest, especially if the ownership level will have an important impact on use. Second, it is sometimes believed that disaggregation may oiften have a higher level of parameter stability (Wheaton 1982). This is due to the idea that disaggregation may suggest new exogenous variables which are important predictors in each component equation. Third, disaggregation may also be important if structural relationships exist among the endogenous variables (Hensher & Smith 1986).

utilisation with particular reference to petrol. Hensher, Smith, Milthorpe and Barnard (1988) and Hensher, Smith and Milthorpe (unpublished) have developed and estimated a series of interrelated dynamic demand models for household sector vehicle ownership and use.

Cars

A longitudinal data set (1981–1985) of very rich panel data was collected from a sample of households in Sydney. The models are dynamic in that lagged experiences and future expectations are built into the models, enabling us to derive short-term and long-term elasticities. The models have a four-year lag, consistent with Dahl's (1986) view that the median lag in adjustment in the United States is 2 to 4 years. The lags in adjustment determine when a policy will take effect. The models and results are set out in detail in appendix II (drawn from Hensher, Smith and Milthorpe, unpublished).

Fleet size and vehicle use elasticities with respect to fuel prices are obtained which, together with fuel efficiency elasticities with respect to fuel price, can be used to derive the fuel-price elasticity of demand for petrol.

Additional evidence on elasticities of vehicle use with respect to fuel cost, derived from a single cross-section, is given by Hensher and Smith (1986), where the estimate varies from –0.22 to –0.31. The weighted (by fleet size in each household) fleet size elasticity is –0.31; the weighted vehicle use elasticity is –0.26 (the latter given in Hensher and Smith 1986).

In order to obtain an estimate of the fleet fuel efficiency elasticity, we ran a simple ordinary least squares regression on ABARE time-series data (1976–1988), and obtained 0.09. This compares with the range of 0.06 to 0.08 reported in Greene (1989b), where he studied the role of fuel efficiency versus corporate average fuel efficiency (CAFE) standards in influencing fleet fuel efficiency. Using the Sydney panel data for this study, Hensher estimated 0.11, with the following model:

$$\begin{gathered}\text{Fuel efficiency per vehicle (litres per 100 kilometres)} = -0.076706 \\ -\,0.004841\ ln\ \text{(VKT in thousands)} + 0.000945\ ln\ \text{(vehicles per household)} \\ +\,0.11448\ ln\ \text{(petrol cost in cents per kilometre)} - 0.000184\ ln\ \text{(household} \\ \text{income)} \qquad R^2 = 0.97\end{gathered}$$

We have taken Greene's CAFE-constrained estimates (those based on manufacturers where fuel efficiency standards are operative), in contrast to the unconstrained estimate of 0.2. Thus there is some correspondence. Greene and Roberts (1984) report an estimate of 0.5 for new vehicles, supporting evidence reported in Dahl (1986, table 1 – reported in appendix III); a much higher than expected figure compared to the estimate for the entire stock of new and used vehicles.

If we combine these three elasticities, we get a petrol consumption elasticity with respect to fuel price of (–0.26) – (+0.09) + (–0.31) = –0.66. In time-series of cross-section data, as a time-series gets shorter and the cross-section gets larger with more data variation, the cross-sectional differences seem to dominate and longer-run adjustment is captured. The four-year Sydney panel data set, with over 1300 households per wave, is of this form.

This result of –0.66 is substantially higher than the estimate of –0.25 derived directly using the ABARE data, and that of Caddy (1989). But note that it is very similar to the mean estimate of –0.71 obtained by Goodwin from 45 time-series studies and –0.84 for 8 cross-section studies. Dahl's average was –0.6, from a large number of studies from models with long-run flow, household, long-run distributed lags and non stock-flow models (Dahl 1986). Details of many of these studies in the literature are given in appendix III.

To help us in gauging the reliability of the –0.66 estimate, we identified the best estimates from the extant overseas literature.

Using overseas evidence the resulting elasticity of petrol consumption with respect to price is –0.54, that is, (–0.26) – (+0.21) + (–0.07). The latter result for fleet size is derived from 10 studies reported by Goodwin (1988). The vehicle use result is derived from an assessment of a number of studies reported by Drollas (1984), Goodwin (1988), Greene and Hu (1982), Vaes (1982) and De Jong (1989), and the fleet fuel efficiency estimate is obtained from Greene (1989b).

We have very strong evidence from a large number of sources to support the suggestion that the petrol price fuel demand elasticity lies in the range of –0.54 to –0.71.

Donnelly (1983) is the only known Australian study which obtained direct estimates of petrol price demand elasticities, obtaining –0.42 for Australia as a whole, with a block of low values for New South Wales, Victoria, Queensland and South Australia (–0.38 to –0.46), and a block of one high value for Western Australia and Tasmania (–1.03). This figure of –0.42 is directly comparable to –0.25 from re-estimation on the ABARE data.

Donnelly used the technique of seemingly unrelated regression (SURE) to obtain parameter estimates. SURE was applied with the assumption of no serial correlation, but spatial correlation between the States of Australia. Donnelly also obtained an ordinary least squares estimate for Australia of -0.67, significantly higher than the –0.42, which for automotive gasoline is the reverse relativity to that found in the estimation of the ABARE data by ordinary least squares and two-step least squares reported herein.

In choosing between the evidence derived from direct estimation (–0.25 to –0.42 for Australia) and indirect evidence derived from three behaviourial relationships underlying consumer energy consumption (–0.661 for Sydney, –0.641 for Australia, and –0.54 for overseas countries), we need to document the advantages of estimating component demand equations, and not simply estimating gasoline demand directly.

Disaggregate models are generally believed to have a higher level of parameter stability, due to the fact that disaggregation may often suggest new exogenous variables, which are important predictors of each component equation. This is certainly the case when one compares the Sydney models with their large number of influencing effects relative to the single equation fuel demand specification. Disaggregation may also be important if structural relationships exist among the endogenous variables.

When the price of petrol increases, a whole sequence of behaviourial responses is set in motion, whereby individuals start to drive less, to drive fewer kilometres more carefully, to replace their less efficient vehicles with more fuel efficient vehicles, and even to own fewer vehicles than they would have done otherwise.

If the structural relationships are complex and important, then the typically simple form of the aggregate time-series models, used to obtain direct estimates of fuel-price demand elasticities, fails to accommodate the interdependencies and functional relationships embedded in the system of behaviourial equations. There is some very convincing evidence to support this statement.

If one were to begin with the fully specified structural system and to derive a reduced form which is consistent with the initial set of relationships, the reduced form single equation would typically be quite complex, with non-linearities in parameters and composite structural parameters embedded within each parameter to be estimated. If the directly estimated energy demand model were derived in this way then we might expect a considerable convergence of evidence from both approaches.

The study undertaken by Drollas (1984) is the only known effort to do this, giving a complex reduced-form single equation (Drollas 1984, equation 12, p. 75). His model is estimated with time-series data for the period 1950–1980. The final estimates of the fuel-price elasticity vary from –0.55 to –0.82, depending on the country.

This evidence provides strong support for the selection of a long-run petrol price elasticity of demand lying in the vicinity of –0.66, in preference to the result based on what could fairly be called naive aggregate reduced-form specifications such as ABARE (1989), Donnelly (1983), and all the pre-1980 econometric studies in Australia. The model described by Caddy, despite its structural character, appears to be somewhat limited in respect of the specification of the lag structure; which may be one of the reasons for the low fuel-price elasticity.

Drollas illustrates another reason why elasticities are higher: this results when proper allowance is made for long-run adjustments in the motor gasoline equation that is derived as a reduced-form specification from a properly specified set of structural equations which define the real behaviourial relationship influencing the demand for transport fuel. Dahl (1986) indicates that higher elasticities from simultaneously estimated models are consistent with simultaneous systems bias toward zero in the single-equation case. The ideal data for capturing long-run adjustment and hence long-run elasticity is a panel up to 10 years with a rich (dominating) cross-section.

If this rationale is accepted for petrol, then in the absence of any evidence on diesel in road transport, we believe it reasonable to place the diesel fuel demand elasticity for road transport in a range which is slightly lower than for petrol, with a preferred mean estimate of approximately –0.55.

Sweeney, a well known commentator on energy economics, stated in 1984 that long-run delivered elasticity of demand for gasoline is probably in the –0.6 to –1.0 range (Sweeney 1984, p. 37). The evidence presented above for gasoline is consistent with this viewpoint.

What we have also identified is a particular concern with the majority of the studies based on naive aggregate econometric specifications of fuel demand models of a reduced form, which have no proven derivation from a behaviourally plausible set of associated structural equation relationships. Dahl (1986) adds the further point that stock-flow models tend to give at most short-run estimates, unless estimated on a data set in which cross-section differences dominate.

Alternative fuels

The issue of alternative fuels needs to be briefly considered, although up to the year 2000 it is reasonable to assume that very little will change other than a switch from leaded to unleaded petrol. We recognise the potential for new fuels and flexible fuelled vehicles in the early decades of the twenty-first century.

Greene (1989c) studies the choice between leaded and unleaded petrol in the United States where, unlike Australia, one can use either fuel in the given vehicle. Not surprisingly he found that, in the absence of legal restriction, the own-price elasticities are inversely related to market share. Thus own-price elasticities decrease rapidly with increasing market share.

Greene found that a 1 per cent decrease in the price of unleaded regular in 1983 would result in a 34 per cent increase in market share at a 1 per cent market share (that is an increase from 1 per cent to 34 per cent); whereas a 1 per cent decease in price at a 50 per cent market share results in a 17 per cent increase (from 0.5 to 0.58).

This evidence may give us some idea about the potential substitution between LPG and petrol, with the caveat that LPG suffers from the loss of boot space and the concern about safety, which is not a problem with alternative grades of petrol. If LPG was equated to leaded petrol, then a 1 per cent decrease in its price (holding the price of petrol unchanged) would increase its market share by approximately 30 per cent, from 2.2 per cent in 1989 to 2.86 per cent. This is clearly an overestimate for the reasons already cited, but it is indicative, and highlights the point that very large price relativities will have to occur before we can see any significant substitution.

Thus without substantial support from fuel suppliers, government and distributors of fuel, it is unlikely that alternative fuels will make significant inroads on current fuel market shares. The effort required in Australia is almost certainly going to have limited impact (other than market conditioning) prior to the year 2000.

AVIATION TRANSPORT

Aircraft are second to road transport in the consumption of petroleum fuels (see table 3.1). The growth of air travel, however, is considerably greater than that of highway travel (the former measured by passengers or passenger-kilometres; the latter by vehicle-kilometres). Although air travel has increased substantially in the last ten years, the growth of fuel use has been restrained by substantial improvements in aircraft fuel efficiency.

The United States has witnessed an increase in seat-miles per gallon (SMPG) from 26.2 in 1970 to 48 in 1989. New commercial aircraft in 1989 deliver 50 to 79 SMPG, with this expected to increase to 65 to 80 SMPG in the early 1990s, with a total aircraft fleet SMPG of 62 to 68 by 2010 under current industry plans (Greene 1989a).

Even given these encouraging fuel efficiency statistics, overall fuel consumption is still likely to grow due to the increased demand for air travel. The best estimate of overall energy consumption growth in the United States is from 0.8 per cent to 1.8 per cent per year up to the year 2010. This contrasts with the annual rate of growth of 3.9 per cent up to the year 2000 assumed by ABARE (1989).

The US evidence from 1970 to 1987, of an average annual rate of growth of energy use of 2 per cent, suggests that Australia is consuming aviation fuels at a higher growth rate than the United States (possibly because we started at a lower base of traffic and an older fleet).

There are many exciting developments in aircraft technology which can have substantial impacts on fuel efficiency and hence energy consumption. Many of the new developments are unlikely to be on stream until after the year 2000, indeed even after the year 2010. A summary of the major developments is given in appendix I, together with the estimated effectiveness of advanced energy efficiency technology for aircraft in the next 20 years. Our main interest herein is on developments which can impact on energy forecasts up to the year 2000.

In the future, as load factors top out and operational improvements are eaten up by rising air traffic congestion, the movement to larger, technically more efficient aircraft types will become the most important means of improving fuel efficiency. However, although efficiency improvements in the seventies and early eighties were driven by rising jet fuel costs, in the late eighties jet fuel prices declined quite substantially.

This was also reflected in the share of airline operating costs. In the United States in 1978, fuel costs comprised 40 per cent of airline operating costs, making fuel efficiency a paramount consideration in aircraft purchasing, retrofitting, maintenance and operation. By 1988 fuel cost as a share of operating cost had fallen to 18 per cent, and it is expected to go lower still. In the meantime, the costs of aircraft ownership (capital costs) have jumped from 28 per cent to 42 per cent of operating costs, so that the cost of the plane instead of the cost of fuel now dominates airline purchase decisions and aircraft manufacturers' plans.

This changing composition has affected the major manufacturers' decisions on engine technology. In particular, Boeing, Airbus and McDonnell Douglas all decided not to offer more expensive, but more efficient, propfan engines on their 1990s generation aircraft.

Despite today's relatively low energy prices, aircraft fleet efficiency will continue to improve as the newer, more efficient engines and airframes replace older, less efficient equipment. For example, Boeing's new 747–400 (megatop) is 10 per cent more efficient than the 747–300, and the 737–500 offers a 20 per cent fuel economy advantage over the 737–200 it replaces. Our task is to establish the key characteristics of the current and projected (on order) fleets of aircraft which we can expect to see in the Australian skies in the next ten years.

In order to identify the fuel consumption of the Australian passenger fleet, data were compiled on the following items for each aircraft type: fleet size, average hours flown per aircraft, seat-kilometres per 1000 litres of fuel, average airborne speed (kilometre per hour) (not maximum cruise speed as supplied in manufacturer specifications), seats per aircraft, and load factor. The data are reproduced in appendix IV.

Given the dearth of any evidence on price elasticities of demand for aviation turbine fuel (avtur) in both the domestic and international aviation sectors, we undertook some preliminary empirical analysis. A time-series database was developed, drawing on the quarterly data series (1977–88) reported by Cosgrove, Gargett and Viney (1989), unpublished quarterly avtur consumption statistics broken down by domestic and international aviation (supplied by ABARE), and an unpublished avtur real fuel-price series supplied by the Bureau of Transport and Communications Economics. Separate models were estimated for domestic and international avtur demand.

Given that the demand for avtur fuel is determined by the demand for travel, the price of fuel and the fuel efficiency of aircraft, we specified a structural system of equations of the form:

Avtur demand = f(demand for travel, avtur fuel price, aircraft fuel consumption, general health of the economy)

Demand for travel = f(household income, exchange rates, air fare, petrol price, seasonal dummies, special events bias)

Given that the demand for travel is an endogenous influence on energy demand, three-stage least squares (3SLS) is used to obtain parameter estimates. It was not possible to treat fuel efficiency as an endogenous variable, because of the lack of suitable data. Obtaining a suitable measure of fuel efficiency, such as seat-kilometres per litre, requires a substantial amount of basic data collection.

Greene (1989a), however, has shown, for a sample of aircraft in the United States, that the all-up (or maximum landing) weight of an aircraft can by itself explain 93 per cent of the variation in fuel use. Given that we have data on the all-up weight of aircraft which since 1977 have operated on the domestic service network in Australia, we use aircraft weight as a suitable proxy for fuel efficiency. Two versions of weight were investigated: for each quarter we obtained a weighted average fleet weight, using as alternative weights the number of aircraft of each type and the number of airborne hours of each aircraft.

Given the difficulty in identifying fleet sizes and airborne hours (or both) for international airlines which are applicable to Australia, the fleet weighted average weight variable was calculated for only domestic services. The airborne hours specification was selected for inclusion in model estimation, even though the partial correlation between the two measures is 0.97.

The final equations are summarised below:

Domestic aviation:

$$\begin{aligned}\ln AD = &-8.46159 - 0.149002 \ln ARFP + 0.0553705 \ln PK \\ &+ 0.348419 \ln AFW + 0.867561 \ln RGDP\end{aligned}$$

$$\begin{aligned}\ln PK = &-0.28.8288 + 5.12733 \ln RGDP - 0.200787 \ln RAF \\ &+ 0.129037 \ln RPP - 0.148932\, D_1 - 0.425704 D_2 \\ &- 0.190482 D_3 + 0.261211 BD + 0.092315 AMD \\ &+ 0.142737 CGD\end{aligned}$$

International aviation:

$$\ln AD = -0.828285 - 0.102374 \ln ARFP + 0.130572 \ln DP + 1.17139 \ln RGDP$$

$$\begin{aligned}\ln DP = &-0.622476 + 0.004010 \ln RTWI + 1.38093 \ln RAF \\ &- 0.1799994 D_1 + 0.0425447 D_2 + 0.478477 D_3 \\ &- 0.028435 BD - 0.043498 AMD + 0.041005 CGD\end{aligned}$$

where AD is avtur demand; ARFP is avtur real fuel price; PK is passenger-kilometres; AFW is average fleet weight per aircraft; RGDP is real GDP; RAF is real air fare; RPP is real petrol price; D_1 is 1st quarter (of the year) dummy; D_2 is 2nd quarter dummy; D_3 is 3rd quarter dummy; BD is Bicentennial Year dummy; CGD is Commonwealth Games dummy; DP is departing passengers; RTWI is real trade weighted index; and AMD is 1980 airline merger dummy.

Air fares have been treated as exogenous influences, primarily because up to 1990 the domestic aviation market in Australia has been air fare regulated. This means, however, that international air fares, also treated exogenously, are likely to yield downward biased estimates of passenger demand elasticities, which would filter through to impact on the fuel-price elasticities, although given the increasingly smaller contribution of fuel-prices to the cost of operations, it is unlikely to significantly alter the mean fuel price elasticity of energy demand (especially after consideration of the confidence limits on point estimates).

The fuel-price elasticities of avtur demand for domestic and international aviation are respectively –0.15 and –0.10. If we assume that the empirical evidence from the automobile gasoline studies is a guide to the implications on elasticity result of different model specifications (that is stock, flow, lagged), and data specifications (that is household, vehicle, quarterly, annual, cross-section), then these estimates are likely to be on the low side (see also appendix IV, table from Dahl 1986). *Our specification is based on quarterly time-series data with no lag* in prices. In the context of the automobile elasticity evidence, we suggest a mark-up of approximately 20 per cent.

Finally, it must be recognised that although the elasticities derived from historical data are an important source of information for evaluating future energy consumption consequent on fuel price changes, the data are less rich than data available to the airlines themselves. Airlines have access to advance bookings that give (in the short run at least) a better idea of future changes. Computer systems will track frequent-flyer kilometres to determine their effect on future traffic growth. Most importantly, the forecasters have access to future marketing strategies that will help predict areas of growth and movements in fares. That is, airlines are able to make predictions based upon expected business actions, that make it more likely that their forecasts will be accurate.

RAILWAY TRANSPORT (INCLUDING HIGH-SPEED RAIL)

Fuel price elasticities of energy demand are not available for the rail sector. Railway transport in 1988–89 accounted for 3.15 per cent of the total energy consumed in the transport sector (ABARE 1989). Automotive diesel oil accounted for 74.3 per cent of this energy, compared to 78 per cent in 1987–88. Rail accounted for 10.8 per cent of total ADO consumption, with an increased share of this fuel (compared with 8.5 per cent in 1983–84, as shown in table 3.1).

Forecasts undertaken by ABARE and the oil companies in this sector are essentially extrapolative, using advice from State rail authorities, and are accompanied by a statement that the growth in rail fuel consumption is expected *to increase only marginally over the projection period.* This assumption, first stated in 1984 (Department of Resources and Energy 1984, p. 26), has been carried forward in the subsequent revision of projections made by the Department of Primary Industries and Energy and ABARE.

The ABARE forecasts are increasing over time, in contrast to the NIEIR forecasts which are decreasing over time (table 3.1). NIEIR presumably have assumed a sufficiently large improvement in fuel efficiency and fuel substitution towards ADO (and to a lesser extent electricity) to more than offset the growth in traffic.

The Australian Railway Research and Development Organisation's *Energy and Railways* report (ARRDO 1981) appears to be the only relatively recent effort to predict current and future energy demand for the Australia-wide rail system. A State Rail Authority of New South Wales train operation simulation program (MTRAIN) was used to obtain energy forecasts. The IMP econometric model of the University of Melbourne Institute of Applied Economic and Social Research provided macro-economic inputs for predicting the effect of energy price rises. The long-term fuel-price elasticities are not given in any of the reports. Two key equations in MTRAIN are used to obtain predictions of the rolling resistance of trains sets and the fuel consumed per 1000 gross tonne-kilometres of train set. Separate equations were derived for freight and passenger services (full details are given in ARRDO 1981).

The best estimate for 1979–80 is 795 megalitres of equivalent distillate, with diesel comprising 80.57 per cent of the energy consumed. The share of ADO is lower than the Department of Resources and Energy figure of close to 90 per cent.

The forecasts of oil prices used are assumed by ARRDO (1981) to be $50–60 per barrel in 1980 dollars, equivalent to US$29–35 in 1988 dollars (assuming an exchange rate in 1980 close to unity). They also assumed that a price increase may occur gradually at an annual rate of 3 to 4 per cent per year, or there may be a number of large increases up to 1985, levelling off as oil prices approach the costs of alternative fuels.

How wrong they were! This is one of a number of illustrations in the literature of substantial errors made in forecasting future oil prices in studies undertaken in the early to mid 1980s. In another context, the US Federal Aviation Authority forecasts in the early eighties (and even up to 1987) of gross national product, seats per aircraft, trip length, yield, enplanements, load factors and fuel prices, had their greatest percentage difference from what actually occurred in prices: 22.9 per cent in 1986 and 20.079 per cent in 1987. The other items were typically 2 to 3 per cent in error (Transportation Research Board 1989, table 1, p. 13).

One could generally accept the ABARE rail transport energy consumption forecasts, on the basis of very limited plans by the railways to change their technology or increase electrification (plus, for example, the State Rail Authority of New South Wales replacing urban rail with buses from midnight to 6 a.m.), and replacing a number of intrastate services using older diesel trains with the XPT. Light rail systems, suggested for a number of urban areas, are unlikely to lead to any substantial energy changes through the nineties.

There is the possibility, however, of some substantial overall energy savings if the Very Fast Train (VFT) commences operations between Sydney, Canberra and Melbourne. The current planned start-up date is 1997. The impact will be

TABLE 5.1 ENERGY USE, CARBON DIOXIDE EMISSIONS AND RATIOS FOR MAJOR TRANSPORT MODES

Mode	*Energy (MJ per pass-km)*	*Ratio*	*Emission (kg CO_2 per pass-km)*	*Ratio*	*Energy source*
Car	1.8–2.4	3–4	0.13–0.17	2.4–3.2	Motor spirit
Plane	2.1–4.1	3.4–6.7	0.13–0.25	2.4–4.7	Jet fuel
VFT	0.83	1.36	0.068	1.28	Electricity generation existing plant 33 per cent efficiency
VFT	0.61	1	0.053	1	Latest technology 45 per cent efficiency
VFT	0.46	0.75	0.042	0.8	Potential technology 60 per cent efficiency

pass-km Passenger-kilometres.
VFT Very fast train.

Note The latest estimates *(VFT Project Evaluation,* VFT Joint Venture, Canberra, November 1990) for the VFT are for primary energy consumption of 0.27 kilowatt-hours per passenger-kilometre (equivalent to 0.97 megajoules per passenger-kilometre) and 0.109 kilograms of carbon dioxide per passenger-kilometre. These values are somewhat higher than those in VFT (1989).

Source VFT Joint Venture (1989, table 11, p. 89). Reproduced with permission.

on energy consumption in aviation and private road transport, with some minor adjustments to rail overall. Here we have one very real benefit through modal substitution. There would be a reduction in petroleum fuel use, but an increase in electricity demand (derived from brown coal, black coal, oil and natural gas).

Estimates by the VFT Joint Venture (1989) suggest that based on today's technologies for all transport modes, the VFT can have a range of efficiency ratios of between 140 per cent and 310 per cent in transport gas emissions per passenger-kilometre when compared with a car or jet plane (table 5.1). The potential for further improvement is greatest for the VFT, as new technologies can increase the efficiency of electricity generation (suggested as 33 per cent to 45 per cent with the latest technology, to as high as 60 per cent with future three cycle generation).

It is claimed that power stations can potentially remove other gases more effectively than cars and jet planes, giving a potential VFT carbon dioxide emission efficiency ratio as high as 200 to 500 per cent (VFT Joint Venture 1989).

If the forecast of traffic diverted from existing modes is accurate (Hensher, Gunn & Brotchie 1989), then we can expect significant savings in energy consumption in the Sydney–Canberra–Melbourne corridor, the most heavily trafficked interurban corridor in Australia. Around 4.1 million of the 11.3 million Sydney–Melbourne equivalent trips (that is, excluding induced traffic) are forecast to travel by the VFT in 1995, with the majority of this traffic diverting from car and air travel.

The potential gain in energy efficiency of the VFT is reinforced by recent US evidence, in the context of the proposed high-speed rail service in Florida. Lynch (1990) suggests that conventional steel track and Maglev high-speed rail systems enjoy a gross energy consumption efficiency (measured in BTU per passenger-mile) of between four and five times that of the aeroplane, and at least twice that of a car (Lynch 1990, tables 5 and 6).

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

The impetus for this study was the desire to investigate the impact of a number of transport fuel pricing and taxing regimes on greenhouse gas emissions contributed by the Australian economy. The transportation sector presents substantial challenges to a policy strategy to encourage transport users to reduce these emissions.

These challenges arise from the high expectations that individuals and businesses have about the quality of transport services available to them, the difficulty of coordinating decision making given the fragmented nature of most of decision making in this sector, and the long lead times, long lifetimes and large capital investments required in the sector.

Early investigations into the impact of pricing policies consistent with reducing carbon dioxide emissions by approximately 20 per cent of 1988 levels by the year 2005 (the Toronto Conference target) have not been encouraging. Marks and Swan (1989) suggest that to attain the Toronto target in 2005 would require a minimum 3.6 per cent per year increase in fuel costs to road transport via taxation, assuming a long-run fuel-price elasticity between –0.3 and –0.6. This in turn would reduce the base forecast of GDP growth by 0.03132 percentage points per year to 3.4087 per cent (the base being 3.44 per cent).

Evidence in the United States (for example, Greene 1989b) suggests that the taxation route is far less successful in achieving energy conservation than the imposition of fuel efficiency and emission standards (such as corporate average fuel economy), targeted toward the small number of decision makers who produce transport vehicles.

An unpublished econometric inquiry by the US Office of Congress and Budget (reported at the January 1990 Transportation Research Board Annual Meeting in Washington, D.C.) into the possible impacts of a 'carbon charge' is not very encouraging. Two charge levels per carbon-ton were investigated: US$100 and US$300, equivalent to an additional price at the retail pump of US35 cents per gallon and US$1 per gallon.

A US$100 charge per carbon-ton is equivalent to US$27 per ton of carbon dioxide. Weighting the carbon dioxide charge by the amount of carbon emission produces a carbon charge of US$2.23 per million BTU for oil (noting that there would be a higher charge for coal), which would lead to an average increase in energy prices in the transport sector of 24 per cent (compared to 55 per cent in the industrial sector).

After one year the reduction in carbon dioxide across all sectors is 23 per cent for coal, 7.5 per cent for oil and 2.7 per cent for gas. Total energy consumption is reduced by 9.1 per cent in the year following the introduction of the tax. Carbon dioxide would be reduced by approximately 12 per cent.

The evidence based upon econometric simulation suggests that non-marginal reductions in greenhouse gases would require quite substantial non-marginal changes to fuel prices, if a carbon tax were to be the sole or primary instrument of policy. It has been estimated that the loss worldwide of 7 per cent per year of gross national product in order to defer global warming by 200 years is industrial suicide, especially for the developing economies which are strongly committed to accelerated industrialisation.

However, despite the price insensitivity of the demand of current populations for energy, it is necessary to begin to introduce appropriate price signals which are identified with efforts to reduce greenhouse gases. The real efforts today should be concentrated on a broader set of demand management strategies (including moderate price increases as signals), combined with continuing improvements in the fuel efficiency of vehicles using conventional fuels, and a continuing research program into the economic and emission benefits of alternative fuels. Mechanisms for encouraging consumer adaptation to economically viable alternative fuels should be included in the research program.

What must be said, however, is that although the traditional econometric model serves a useful purpose, it is very limited in respect to an assessment of these new issues. Current demand forecasting models used by economists are driven primarily by price and income. The big impacts include new technologies, promotional strategies and research incentives, all of which are either poorly handled or unable to be handled in the current modelling and forecasting environment.

The challenge is not to singularly identify the role of prices and taxes, but to also identify strategies to make technological change and consumer adaptation a success. The experiences in the seventies and early eighties showed that technological modification, rather than behaviourial modification, is the way to effect energy conservation.

In the Australian context, automobile manufacture and design is very much influenced by decisions in Japan and the United States. Consequently heavy reliance on local fuel price increases may have limited effect if the major automobile suppliers cannot supply the local market with appropriate fuel efficient vehicles.

California has made a start by a combination of price incentives and mandated standards on the mix of fuels in the total automobile vehicle stock over the next

TABLE 6.1 POLICIES FOR THE TRANSPORTATION SECTOR

Policy or activity	*Fuel use*	*Fuel choice*	*Transportation demand*	*Infrastructure development*
Regulation				
Controls	Set emission limits on natural gas leakage to promote operation and maintenance improvements	Modify natural gas utility regulation to promote use of natural gas as a transportation fuel	Support local controls on parking and highway lane use to encourage higher vehicle occupancy and lower emissions per trip	Require Federal and State agencies to consider vulnerability to climate change when planning transportation
Standards	Raise CAFE standards to promote design, production, marketing, and purchase of high-fuel-economy vehicles	Establish equipment standards for vehicles to promote use of alternative fuels with lower green-house gas	Set standards to improve the performance of low-emission modes and, in concert with advertising, make their use more attractive emissions	Develop standard that reduce materials use and associated greenhouse gas emissions in infrastructure development
	Set standards for vehicle maintainability to promote operation and maintenance improvements			
	Impose fuel economy standards for used cars to increase rate of disposal of vehicles that have very low fuel economy			

TABLE 6.1 (Cont.) POLICIES FOR THE TRANSPORTATION SECTOR

Policy or activity	*Fuel use*	*Fuel choice*	*Transportation demand*	*Infrastructure development*
Licensing and certification	Require periodic vehicle inspection, maintenance, and certification to promote operation and maintenance improvements	Certify mechanics and garages to service vehicles that use alternative fuels with lower greenhouse gas emissions		Require consideration of vulnerability to climate change in application for permits to develop major infrastructure
Fiscal				
Prices	Establish a deposit-refund system for CFC refrigerants in mobile airconditioners			
Taxation	Tax petroleum fuels, establsih packages of taxes and rebates or corporate income tax incentives, to promote design, production, marketing, and purchase of high-fuel-economy vehicles	Tax petroleum fuels as part of an integrated package of options to promote use of alternative fuels with lower green-house gas emissions	Provide corporate tax incentives for employers to encourage employees to increase vehicle occupancy and reduce emissions	Surcharge on construction contracts to support demonstration and certification of designs and standards that reduce materials use in infrastructure development
Subsidies	Promote design, production, marketing, and purchase of high-fuel-economy vehicles by taxes and rebates	Subsidise a range of sector activities to promote use of alternative fuels with lower green-house gas emissions, including R&D	Subsidies to promote development of low-emission modes	

TABLE 6.1 (Cont.) POLICIES FOR THE TRANSPORTATION SECTOR

Policy or activity	*Fuel use*	*Fuel choice*	*Transportation demand*	*Infrastructure development*
Direct expenditures	Purchase high-fuel-economy vehicles for government vehicle fleets, and support prototype development to promote design and production of efficient vehicles	R&D to reduce cost of producing alternative fuels with low green-house gas emissions	R&D to understand demand for transportation to permit subsequent formulation of policies to reduce growth in demand	R&D to reduce materials use and associated greenhouse gas emissions in infrastructure development
Information				
Advertising	Advertising and public information to promote purchase of high-fuel-economy vehicles Promote operation and maintenance improvements		Targeted advertising to promote switching from high- to low-emission modes	
Education	Develop and support courses to promote improvements in vehicle operations that reduce emission of greenhouse gases			Encourage exchange of information on materials reduction through limited R&D partnerships in the construction industry Require Federal and State agencies to consider vulnerability to climate change when planning transportation infrastructure

TABLE 6.1 (Cont.) POLICIES FOR THE TRANSPORTATION SECTOR

Policy or activity	*Fuel use*	*Fuel choice*	*Transportation demand*	*Infrastructure development*
Moral suasion	Promote operation and maintenance improvements that reduce emission of greenhouse gases		Promote switching from high- to low-emission modes	
Signalling	Require periodic vehicle inspection and maintenance to signal vehicle manufacturers to develop designs that maintain high fuel economy	Promote switching to fuels with lower greenhouse gas emissions, as signal to vehicle manufacturers to produce vehicles that can use such fuels	Increase the tax on petroleum fuels as a sign to local governments to increase efforts to promote use of modes with lower emissions	Require Federal and State agencies to consider vulnerability to climate change when planning major investments in transportation infrastructure, as a signal for them to think about the potential need to adapt
	Tax petroleum fuels to signal vehicle manufacturers to design and produce high-fuel-economy vehicles			
Research, development and demonstration				
Public invention-support programs				

TABLE 6.1 (Cont.) POLICIES FOR THE TRANSPORTATION SECTOR

Policy or activity	*Fuel use*	*Fuel choice*	*Transportation demand*	*Infrastructure development*
Commercialisation policy				
Provision of specialised onformation				
Demonstrations				Demonstrate design and methods to reduce use of materials in infrastructure development

CAFE Corporate average fuel efficiency.
CFC Chlorinated fluorocarbons.
R&D Research and development.

Source US Department of Energy (1989).

ten years. Residents of Southern California who purchase a new automobile satisfying a particular level of fuel efficiency obtain a substantial price rebate. Specific policies for the transportation sector designed to contribute in varying degrees to the reduction of transport emissions are summarised in table 6.1.

The primary task of this study has been to identify the role of fuel prices in determining the long-run demand for the major fuels in the transport sector. It is not possible to derive the necessary elasticities from the available models used by ABARE, the Australian Institute of Petroleum, and NIEIR to forecast energy demand up to the year 2000.

The empirical inquiry detailed in this report finds that fuel-price elasticities should be derived from a set of behaviourial equations which represent the major influences on the derived demand for transport fuels. The direct estimation of an energy demand model is only satisfactory if the reduced-form energy demand equation is derived from the set of structural behaviourial equations.

The recommended fuel demand elasticities for road transport are –0.66 for passenger vehicles (predominantly automotive gasoline) and –0.55 for trucks (predominantly automotive diesel oil). The recommended price elasticities for aviation turbine fuel are –0.12 for international aviation and –0.18 for domestic aviation.

APPENDIX I ADVANCED ENERGY EFFICIENT TECHNOLOGY IN AIRCRAFT

Estimated Effectiveness of Advanced Energy Efficiency Technology for Aircraft
(Source in Parentheses)

Technology	Available Date	Applicability, Comments	SMPG Gain Over 1980's Generation	SMPG Gain Over 1990's Generation
Ultra High Bypass (ducted)	1992 (8) 1995 (1, 7)	Thrust range 20,000 60,000 lbs (1)	10% (12) 15% (15) up to 20% (3) 19 - 21% (2) up to 25% (7) 15 - 30% (18) 10 - 20% (6)	0 - 10%, 17% (6)
Propfan (unducted)	1995+ (7) 2000 (18) [Standard by 2030 (14)]	Thrust range 15,000 25,000 lbs (1) A320, 157, MD 80 not likely to be reengined with PFs (4) Cost $10M, 2X JT8D (8) Medium to low Thrust - not suitable for 2 ENG WB	20 - 40% (2) 47% over 60's (4) 50% over 60's - 70's (3) 40 - 50% (6) 20 30% (8) 30 - 35% (17) 35 - 40% (16) 40% (19)	25 28% (2) 10 - 30% (4) 20 - 30% (3) 9% over UHB (5) 20% (12) up to 30% (13) 23% (15) 23% (16) 25% (19)
Weight Reduction, Materials	2000+ (11)	up to 35% (21) up to 30% wgt red (17) up to 30% wgt red (11) 15 25% wgt red (16) 11 20% wgt red (20)	25% (21) 22% 11 18%	17.5% (22) 15% (22) 15% (22) 7.5 12.5% (22) 7 10% (22) 10 15% fuel savings (20)
Elect. Controls	1990 (20)			9% (20)
Active lift/drag ctl	1990 (20)			7% (20)
Large Eddy Break-Up	2000+	up to 15% drag red		
Hybrid Laminar Flow Control		10 - 20% (17) up to 40% drag red (14)	15 - 20% (19)	

Technology	Available Date	Applicability, Comments	SMPG Gain Over 1980's Generation	SMPG Gain Over 1990's Generation
Advanced Aerodynamics	2000 + (9)	All wing aircraft and laminar flow control	up to 30% 33% (9)	15 - 30% (17)
Engine Thermodynamics	2000 (10) 2000 + (12)	core, low spool and nacelle (16) increased temperatures, materials and improved machinery	35 - 40% (16) up to 20% (10) up to 20% (12) 20% (14)	SFC 24 - 29% (16)
Overall Specific Fuel Consumption Improvement Estimates		10 - 35% by 2000 (16) 50%, 1% 1/2%/yr through 2038 (14) 200 SMPG early 21st Century		

1 "Rolls Skeptical About Early Propfan Service Introduction," Aviation Week and Space Technology, April 13, 1987, pp 68-70
2 "Pratt's Cautious Research Reflects Uncertain UHB Market," Aviation Week and Space Technology, April 13, 1987, pp 70-74
3 "NASA Continues UHB Development R 6," Aviation Week and Space Technology, April 13, 1987, p. 56.
4. "No 2 UDF Engine Prototype Will Fly on MD 80 by June," Aviation Week and Space Technology, April 13, 1987, pp 58 67.
5 "Airframe Manufacturers Near Landmark UHB Decisions," Aviation Week and Space Technology, April 13, 1987, pp 52-55.
6 "Experimental PW Allison Propfan Begins Flight Testing," Aviation Week and Space Technology, April 17, 1989, pp 63-64
7 "Ultrahigh Bypass Engines Will Enter Commercial Service by Late 1980's," Aviation Week and Space Technology, March 9, 1987, pp 189-190
8 "Propfans for the 1990's," Graham Warwick and Julian Moxon, Exxon Air World, vol 39, no 3, 1987, pp 13-16.
9 "Airline Aircraft - III," Alan Blythe, Exxon Air World, v 41, no 1, 1989, pp 34 35
10. "Aircraft Engines - I," Hans von Ohain, Exxon Air World, v 40, no 2, 1988, pp.
11. "Airline Aircraft - I," John M Swihart, Exxon Air World, v 40, no 2, 1989, pp 10 14.
12. "Aircraft Engines - II," Martin G. Smith, Jr., Exxon Air World, v 40, no 3, 1988, pp 20-22
13. "Aircraft Engines - III," Daniel C Mikkelson, Gregory M Reck, vol 40, no 3, 1988, pp 22 26
14. "Airline Aircraft - II," Dieter Schmitt, Exxon Air World, vol 40, no 3, 1988, pp
15. "Aircraft Engines - IV," Philip C. Ruffles, Exxon Air World, vol 41, no 1, 1989, pp 36-38
16. Personal Communication, Mr Larry Fishback, NASA Lewis Research Center. Also, "Aeronautical Technology 2000. A Projection of Advanced Vehicle Concepts," A Report of the Aeronautics and Space Engineering Board, National Academy Press, Washington, D C, 1985
17. Swihart, John M, "Aeronautical Developments for the 21st Century," Wright Brothers Lectureship in Aeronautics, St. Louis, MO, September 14, 1987, published by The Boeing Co., Seattle, WA
18. "Denver to Seoul, Nonstop," Forbes, May 29, 1989, pp 284-288
19. "Saving Fuel in Flight," by Christopher Vaughn, Science News, vol 134, pp 266-269, October 1988.
20. "Profile of Commercial Aviation Technologies," Energy and Environmental Analysis, Inc., Arlington, VA, prepared for Energy Information Administration, U S Department of Energy, Washington, D C, November 1982.
21. "Douglas Focuses on Acquisition Cost of Late 1990's Civil Transports," Bruce A. Smith, Aviation Week and Space Technology, pp 37 40, November 21, 1988
22 Based on the regression analysis described in the appendix we estimate that the elasticity of fuel use with respect to airframe weight ranges from 0 25 to 0.5 depending on aircraft size Since aircraft trends indicate increasing size, and to use a round number, we assume an elasticity of 0.5 Also, this seems conservative in relation to the few estimates found in the literature

Source: Greene (1989a)

APPENDIX II THE SYDNEY AUTOMOBILE DEMAND MODEL SYSTEM: EMPIRICAL RESULTS FOR THE DYNAMIC VEHICLE CHOICE AND USE MODELS

The dynamic specifications of the vehicle choice and use models reported in this appendix break new ground in our understanding of the household sector's demand for automobiles. We present vehicle type-mix choice results for households with one, two and three-plus private and household business registered vehicles, followed by the results of the joint fleet-size/body mix choice. The dynamic vehicle use model is then presented, followed by the presentation and discussion of the most important elasticities of vehicle choice and use. The models and results presented herein are an extract from Hensher et.al (1990)

Vehicle Type Choice Results

Empirical dynamic vehicle type (mix) choice models are given in Table A2.1. Separate type-choice models are estimated for one, two and three-or-more vehicle households with fleet-size specific selectivity terms: used to link these models with the household level vehicle use model. The latter comprises four equations with equality restrictions on parameters across equations. Results are based on the 1172 households which participated in all four waves of a panel of Sydney Households over the period 1981-1985. All dollar items are expressed in 1981 values.

The reported type choice results are given for the pooled four waves, corrected for heteroscedasticity, with the heteroscedasticity weights based on the VFLTYP parameter. The optimal value of θ is 0.1, which suggests that the response reaction in automobile type-choice holdings to a change in type choice determinants is predominantly instantaneous with a small additional one lag reaction. However, we found a rather flat log-likelihood surface for values of between 0.1 and 0.9. The statistical significance of individual effects and overall goodness-of-fit of these models are impressive. The pseudo-R^2s for one, two, and three-plus vehicle models are respectively 0.55, 0.57, and 0.53 (the equivalent overall fits for the static specifications were respectively 0.18, 0.28 and 0.27). We have identified in the extension to a dynamic specification the importance of *expectations* and *experiences* in vehicle choice decisions. Through the application of a lagged index structure we have been able to introduce a dynamic specification into all the explanatory variables, greatly improving the range of intertemporal influences.

Table A2.1 Dynamic Vehicle Type (Mix) Choice

($\theta = 0.1$, T - expectations, R = experience)

Expectations Effects:	Acronym	1 Vehicle	2-Vehicles	3+ Vehicles
Vehicle mix capital cost [$/$10^3$]	PRICE.T	-.000077	-.000098	-.000073
		[-5.51]	[-4.62]	[-5.92]
Vehicle mix capital cost [$/$10^3$]	PRCHNC.T	0.002485	0.002201	0.001105
* household income [$/yr*$10^{-5}$]		[4.94]	[4.11]	[5.39]
Fuel cost [c/km*10^{-4}*typical	VFLTYP.T	-.002283	-.002113	-.001463
use [km/year]		[-11.4]	[-6.59]	[-6.61]
Household size*[Σseats]$^{0.5}$	SQCAPS.T	0.271708	-	-
		[9.60]		
Total vehicle seatspace if household	STSPC.T	-	0.002804	-
size > 4 persons			[2.18]	
Experience Effects:				
No. of vehicles in mix with weight <100 kg	VMASS1.R	-1.48975	-1.17758	-.59547
		[-22.3]	[-9.03]	[-6.40]
No. of vehicles in mix with weight 1000 to	VMASS2.R	-	-1.25575	-1.34850
1200 kg			[-9.61]	[-13.02]
No. of vehicles in mix with luggage capacity	LUGCP1.R	-.55642	-	-.76377
$\leq$0.4m^3		[-5.80]		[-8.19]
No. of vehicles in mix with luggage capacity	LUGCP2.R	-1.19552	-	-
0.41-0.1m^3		[-13.9]		
Total luggage capacity of mix [m^3]	LUGCAP.R	-	-.91816	-
			[-10.0]	
No. of vehicles in mix with insurance	INSRT1.R	-1.29207	-	-
rating $\leq$2		[-14.0]		
No. of vehicles in mix with insurance	INSRT2.R	-1.41450	-	-
rating 3-6		[-20.2]		
No. of vehicles in mix with 4 cylinders	CYLND4.R	-	-.61204	-
			[-4.50]	
No. of vehicles in mix with 6 cylinders	CYLND6.R	-	-1.58391	
			[-11.3]	
Average mix acceleration from 0 to 100	AVGACC.R	-.47596	-.64241	-.58626

km/hour [seconds]			[-30.7]	[-16.7]	[-12.9]
Total seatspace if household size >4		STSPC.R	-	-	-.009322
					[-5.00]
No. of vehicles in mix with manual		MANUAL.R	-	-	-.86525
transmission					[-10.6]
Log-likelihood at convergence			-2774.42	-1449.20	-494.79
Log-likelihood at zero			-6115.63	-3358.20	-1054.53
Likelihood ratio index			0.55	0.57	0.53
Sample size			2552	1401	441
Heteroscedasticity correction	Wave 4:		0.99990	1.00063	0.99975
weights	Wave 3:		0.99890	1.00828	0.99749
	Wave 2:		0.98994	1.06115	0.97468
	Wave 1:		0.89143	1.50346	0.70715

Table A2.2 Type Choice Basic Statistics [$81: private and household business registered vehicles] [CH=chosen]

	81		82		83		84	
	ALL	CH	ALL	CH	ALL	CH	ALL	CH
1 Vehicle:								
PTCSKM.T [c/km]	5.221	4.751	4.981	4.562	4.746	4.341	4.823	4.374
PRICE.T [$\$*10^{-3}$]	5.724	4.433	5.681	4.577	5.530	4.464	5.536	4.635
PRCHNC.T [$\$*10^{-3}$]								
*[$\$*10^{-3}$]/100	1.480	1.188	1.422	1.217	1.254	1.095	1.252	1.137
VFLTYP.T [$\$/100$]	7.997	7.300	7.615	7.013	7.132	6.564	7.179	6.547
Hhld income [mean=24037]	22723		24913		22777		22631	
Sample Size	7216	656	7073	643	6952	632	6831	621
2 Vehicles:								
PTCSKM.T [c/km]	10.435	9.673	10.007	9.234	9.474	8.789	9.631	8.968
PRICE.T [$\$*10^{-3}$]	11.273	9.061	11.550	9.461	11.036	9.073	11.424	9.810
PRCHNC.T [$\$*10^{-3}$]								
*[$\$*10^{-3}$]/100	3.883	3.210	3.861	3.333	3.566	3.059	3.755	3.387
VFLTYP.T [$\$/100$]	14.02	13.05	13.32	12.33	12.43	11.55	12.62	11.77
Hhld income [mean=33113]	34314		33359		32179		32578	
Sample Size	3883	353	3817	347	3828	348	3883	353
3+ Vehicles:								
PTCSKM.T [c/km]	16.98	15.89	16.41	15.36	15.54	14.66	15.74	14.91
PRICE.T [$\$*10^{-3}$]	18.62	16.30	18.40	15.94	17.69	14.44	18.19	14.71
PRCHNC.T [$\$*10^{-3}$]								
*[$\$*10^{-3}$]/100	9.286	8.249	8.561	7.675	7.660	6.690	7.474	6.167
VFLTYP.T [$\$/100$]	21.58	20.17	19.73	18.50	18.80	17.77	19.24	18.19
Hhld income [mean=43940]	48827		45115		42298		40051	
Sample Size	1111	101	1243	113	1254	114	1243	113

Notes:

1: The mean values relate to the unweighted lagged index; so they are 1.1 of the current period value.

2: The mean values are unweighted (i.e. prior to the application of the heteroscedasticity weight reported in Table A2.1)

All three type (mix) choice models have variables representing the major categories of influence: financial performance, passenger carrying capacity, luggage capacity, and class of vehicle. Vintage and make dimensions are excluded as explanatory variables because they are part of the definition of the choice alternatives, which are unranked. Thus these models can provide predictions of household choices of vehicle type (mixes), defined by make, model and vintage. Some of the static models in the literature incorrectly include vehicle age in the definition of the choice variable and as an explanatory variable. The typically dominating t-value for the variable suggests a misspecification problem. The empirical investigations which led us to the selection of the final models found that the financial effects are best specified as expectations indices, whereas vehicle quality attributes are stronger influences in the form of experience effects. Interpretation of the expectations variables is straightforward.

The strong statistical significance of the experience effects is indicative of the important role of habit in shaping type-choice holdings. All these effects have the correct negative sign. Taking the luggage capacity variables as an example, the negative sign on the experience parameter suggests that there is a greater likelihood of holding a vehicle (mix) in the current period that has a similar luggage profile as the vehicle (mix). The higher parameter estimate for LUGCP1.R compared to LUGCP2.R in the one vehicle model suggests that the experience effect is stronger for a given level of similarity with vehicles possessing luggage capacities in the range 0.1 - 0.4 cubic metres than in the range of > 4 cubic metres. In contrast the parameter estimates on the insurance rating experience variables take about the same value regardless of the insurance category.

Vehicle Body Mix and Fleet Size Choice Results

The dynamic fleet-size/body-mix choice model is jointly estimated by the full information maximum likelihood (FIML) procedure, with each variable defined as a lagged exogenous index of the expectations form. The lagged structure found to give the highest likelihood for type choice ($\theta = 0.1$, 1 lag) was also applied to the higher level joint choice of fleet size and body mix. The set of influences on dynamic choice were based on the findings from the static specification reported in Hensher et. al. (1988). After further exploratory analysis we selected a final model which had these same influences (associated with the same body mix alternatives), plus a proxy *initial conditions* variable, defined as the household's history with vehicles prior to the panel period. This variable is specified as the number of vehicles the household has held since the household was formed. The final model is summarised in Table A2.3 together with summary statistics in Table A2.4.

The overall fit of the dynamic fleet-size/body-mix choice model is much improved over the static model (reported in Hensher et.al 1988) with the likelihood-ratio index increasing from 0.17 to 0.42 (250 per cent higher). All the parameter estimates of the exogenous variables are strongly significant (except for the rental accommodation on dummy variable associated with the zero-vehicle fleet size) and of the expected signs. Two of the three fleet-size specific constants are statistically non-significant.

The inclusive values associated with the linkages between type-mix choice and body-mix choice, and between body-mix choice and fleet-size choice are both highly significant and positive. Although the body mix inclusive value lies within the 0-1 interval, thus satisfying the necessary and sufficient conditions for a random utility specification being consistent with utility maximisation, the type-choice inclusive value is outside the range (= 1.43). We found that this mean parameter estimate was extremely robust to different starting values on the FIML estimates, and to the inclusion/exclusion of selective exogenous variables. Borsch-Supan (1987) has shown that an inclusive value greater than unity can still lead to a nested multinomial logit model which can be reconciled with random utility maximisation. It becomes an empirical issue associated with the properties of the particular data set. He has shown as a local sufficiency that the parameter of inclusive value can exceed unity and be consistent with random utility maximisation provided all mixed partial derivatives of the cumulative distribution function (cdf) up to the order of the choice set are non-negative in the open interval containing all data points, and if the cdf does not exceed unity at a point in the unit interval. We applied this test and were able to corroborate this local sufficiency for our data. However, Train et al. (1987) have recently stated that the static random utility theory (for which the global and local sufficiency conditions have been developed) does not represent dynamic aspects of vehicle choice, and by implication it is an open question as to the applicability of this condition in a dynamic choice context. From a purely statistical viewpoint, the inclusive value parameter indicates relative substitutability within and among nests, and neither possibility can be ruled out a priori.

Table A2.3 Dynamic Joint Fleet Size-Body Mix Choice

$\theta = 0.1$, all variables are of the expectations form. 9 alternatives, 4688 observations. Alternatives: O = zero vehicles. 1S = 1 sedan, 1W = 1 wagon, 1 O = 1 other vehicle, 2S = 2 sedans, 2 [W,S] = 1 wagon plus 1 sedan, 2 O = 2 other vehicles, 3S = 3 sedans, 3 O = 3 other vehicles. The fleet sizes are defined in terms of privately registered and household-business registered vehicles, with *other-business* registered vehicles treated exogenously.]

Explanatory Variable	Estimated Coefficient	t-value
Fleet size 3-plus dummy (3S, 3 *O*)	-3.763	-4.61
Fleet size 2 dummy (2S, 2(W,S), 2 *O*)	0.4264	0.75
Fleet size 1 dummy (1S, 1W, 1 *O*)	0.6035	1.23
Number of driver licences (all except O vehicles)	3.5779	10.03
Rent accommodation dummy (O vehicles)	0.4968	1.33
Buy accommodation dummy (2S, 2(W,S), 2 *O*)	0.4508	2.86
Other-business registered dummy (2S, 2(W,S), 2 *O*, 3S, 3 *O*)	-8.509	-13.11
Other-business registered dummy (1S, 1W, 1 *O*)	-5.331	-10.12
Number of commuters working in and adjacent to central city (1S, 1W, 1 O, 2S, 2W, 2 O)	-0.596	-4.11
Annual household income ('00's) (2S, 2(W,S), 2 *O* ,*3S, 3 O*)	0.5818	9.23
No. of full and part-time workers (2S, 2(W,S), 2 *O*, 3S, 3 *O*)	1.1002	9.35
Age of household head (3S, 3 *O*)	0.6154	6.14
No. of children (1W, 2(W,S), 2 *O*)	-0.180	-7.24
Lifecycle stage dummy:		
Young adults, no children (0, 1S, 1W)	2.595	11.86
Adults 35-64 yrs old, no children (0,1S, 1 O)	2.376	14.21
Retired persons, no children (2S,2(W,S), 2 O, 3S, 3 O)	-4.199	-6.39

Previous vehicle history		
(all except 0 vehicles)	0.136	4.09
Inclusive value body mix	0.559	25.7
Inclusive value type mix	1.431	38.9
Log-likelihood at convergence	-6019	
Log-likelihood at zero	-10300	
Likelihood ratio index	0.42	
Heteroscedasticity correction weights:		
	Wave 4	0.99956
	Wave 3	0.99559
	Wave 2	0.95499
	Wave 1	0.34667

Table A2.4 Fleetsize-Body mix Basic Statistics [All dollar items are in 1981 values].

Variable	81	82	83	84
Proportion of hhlds in fleets containing:				
a sedan	0.803	0.776	0.759	0.742
a station wagon	0.209	0.225	0.224	0.242
a panel van	0.037	0.041	0.026	0.027
a light commercial	0.034	0.039	0.052	0.067
a small truck	0.038	0.037	0.032	0.032
an utility	0.021	0.030	0.032	0.030
an other-business registered sedan	0.095	0.080	0.075	0.080
an other-business registered wagon	0.030	0.023	0.029	0.027
an other-business registered other veh.	0.013	0.011	0.013	0.012
zero vehicles	0.053	0.059	0.067	0.073
one vehicle	0.560	0.549	0.539	0.530
two vehicles	0.301	0.296	0.297	0.301
three or more vehicles	0.086	0.096	0.097	0.096
one sedan	0.435	0.405	0.391	0.369
one wagon	0.101	0.113	0.111	0.119
one *other* vehicle	0.024	0.031	0.038	0.041
two sedans	0.163	0.155	0.157	0.151
Table A2.4 continued				
one sedan plus one wagon	0.061	0.063	0.066	0.072
two *other* vehicles	0.078	0.078	0.074	0.078
three sedans	0.038	0.040	0.044	0.035
three *other* vehicles	0.049	0.056	0.053	0.061
Type choice inclusive value:				
one sedan	-1.165	-1.034	-0.873	-0.983
one wagon	-1.664	-1.334	-1.176	-1.228
one *other* vehicle	-3.112	-2.625	-2.416	-2.501
two sedans	-2.657	-4.342	-4.527	-4.635
one sedan plus one wagon	-2.795	-4.476	-4.691	-4.769

two *other* vehicles	-4.033	-6.052	-6.281	-6.296
three sedans	-9.626	-6.471	-6.218	-6.246
three *other* vehicles	-8.795	-5.849	-5.614	-5.707
number of driver licences	2.218	2.172	2.155	2.149
proportion of households:				
renting a house	0.187	0.180	0.165	0.166
buying a house [loan being paid]	0.663	0.549	0.538	0.508
with at least one other-business registered vehicle	0.150	0.126	0.126	0.128
number of commuters working in or adjacent to the central city	0.586	0.549	0.431	0.414
annual household income	33318	34984	36441	38687
number of workers [full plus part] time	1.929	1.765	1.694	1.686
age of household head	47.63	48.47	49.36	50.27
number of children in the household	1.289	1.316	1.303	1.275
Proportion of households in lifecycle stage:				
young adults, no children	0.136	0.128	0.118	0.105
adults 35-64 years, no children	0.156	0.171	0.179	0.195
retired persons, no children	0.043	0.051	0.057	0.064
previous vehicle history [no. of vehicles held since first vehicle acquired up to start of panel]	10.09	10.09	10.09	10.09

Notes:

1. The mean values related to the unweighted lagged index; so they are 1.1 of the current period value.
2. The mean values are unweighted (i.e. prior to the application of the heteroscedasticity weights reported in Table A2.3).

Thus, what our results suggest for the type-choice/body-mix interface is that substitution among nests (i.e. from one body mix to another) occurs more readily than substitution *within* nests (i.e. from one type mix alternative to another). For example, moving from one sedan to one wagon or one sedan to one *other* vehicle, or from one wagon to one *other* vehicle is an easier substitution than going from say one sedan of type x to one sedan of type z. However for the body-mix/fleet size interface, substitution within nests (i.e. from one fleet size to another) occurs less readily than substitution within nests (i.e. from one body-mix alternative to another). All the exogenous variables except body-mix inclusive value enter into the indirect utility expressions for the 9 body-mix alternatives. The probability of fleet-size choice is determined solely by the inclusive values associated with each body-mix node. For the degenerate node of zero vehicles, the inclusive value is $\ln[\exp V_{BM} = 0] = V_{BM} = 0$. These results seem eminently plausible.

The joint fleet-size/body-mix choice model is defined on privately-registered and household-business registered vehicles. *Other-business* registered vehicles are excluded from the definition of the endogenous choice variable because households typically do not have a choice of whether or not to hold such vehicles. They are treated as exogenous variables. The role of the presence of *other-business* registered vehicles is handled in model estimation by the exogenous inclusion of two dummy variables representing the presence/absence of such vehicles in households with one or more-than-one *non-other business* registered vehicles (Table A2.3). These effects are strong negative influences on the probability of having *additional* vehicles in the private and household-business categories.

The results in Tables A2.1 and A2.3 can be applied to the base data with the sample enumeration method to calculate for each household their probability of each type-mix choice conditional on a body-mix and fleet-size, their probability of body-mix conditional on fleet-size, and then the marginal probability of fleet size (given the exogenously determined availability of other-business registered vehicles). The joint probability of type mix, body mix and fleet size associated with the *chosen* vehicle profile is now utilised to derive for each household the selectivity correction term for inclusion in the dynamic vehicle use model we have opted for the selectivity correction specification which only requires data on the chosen path through the nested choice hierarchy. Hensher and Milthorpe (1987) report empirical evidence based on the panel data which shows that the use of the more complex correction formula proposed by Dubin and McFadden yields virtually identical results. The form of the selectivity term used herein is given in Table A2.6.

Dynamic Vehicle Use in the Household Sector

The final dynamic vehicle use models with selectivity are summarised in Table A2.5. We have reported results based on alternative assumptions on the initial conditions. The dynamic use models are specified in terms of total household kilometres associated with all vehicles. The use of *other-business* registered vehicles is treated endogenously (in contrast to their vehicle choice) since households do have an influence on the pattern and level of use of such vehicles. In Hensher [1985] we have discussed the linkages between the use of each vehicle in a household at a point in time and over time, and have argued that the influence of the use level of one vehicle on the use level of another vehicle in the household's fleet is best studied intratemporally, with the resulting use of each vehicle summing to define the total annual use of all vehicles. The latter is then included in the dynamic use model as the new lagged level of use. Furthermore, for the use module to be compatible with the vehicle choice module, the former needs to be a household-level model. This also resolves a computational problem of identifying the relevant mapping of vehicles through time for calculating the lagged indices, especially the lagged selectivity index.

Table A2.5 Dynamic Vehicle Use Models (1172 households with 0, 1, 2, 3, 4+ vehicles). All dollar items are in 1981 dollars. Dependent variable = annual kms * 10^{-4}.

[EX= exogenous, EN = endogenous; UN = unconstrained, SC = serial covariance. ST = SC + stationarity, ρ = correlation between η_i (the random effect) and the residual disturbance]

	1	2	3	4	5	6	7	8
HKM_o	EX	EN	EX	EN	EN	EN	EN	EN
Ω	UN	UN	SC	SZ	SC	UN	SZ	SC
Constant	0.5558	0.7103	0.6766	0.9933	1.0906	1.2797	1.6621	1.2232
	[5.90]	[6.31]	[6.92]	[8.03]	[8.46]	[5.91]	[9.25]	[8.56]
AGEHD	-.0031	-.0039	-.0040	-.0056	-.0062	-.0164	-.0195	-.0064
	[-2.2]	[-2.4]	[-2.5]	[-2.9]	[-3.1]	[-3.8]	[-5.4]	[-3.3]
DHINC	0.3067	0.3903	0.3569	0.5371	0.5913	0.4193	0.6021	0.6089
	[1.92]	[2.24]	[2.10]	[2.68]	[2.93]	[2.35]	[3.00]	[2.98]
RMAINK	-.1060	-.1136	-.1042	-.1106	-.1109	-.1055	-.1060	-.1101
	[-7.8]	[-8.3]	[-8.0]	[-8.3]	[-8.4]	[-7.5]	[-8.0]	[-8.5]
PTCSK	-.0445	-.0498	-.0510	-.0599	-.0619	-.0469	-.0582	-.0623
	[-3.3]	[-3.5]	[-3.6]	[-3.7]	[-3.8]	[-3.3]	[-3.6]	[-3.9]
NONRRC	0.2806	0.2942	0.2941	0.2975	0.2969	0.2722	0.2823	0.2918
	[4.35]	[4.40]	[4.33]	[4.08]	[4.15]	[4.00]	[3.93]	[4.15]
SELLP	0.2062	0.2447	0.2194	0.2820	0.2970	0.2583	0.3032	0.2992
	[3.31]	[3.64]	[3.31]	[3.75]	[3.97]	[3.78]	[4.05]	[3.99]
CITYAR	-.1562	-.1850	-.1694	-.2176	-.2282	-.1857	-.2254	-.2283
	[-5.0]	[-5.3]	[-5.1]	[-5.6]	[-5.8]	[-5.3]	[-5.8]	[-5.8]

Table A2. 5 continued

	1	2	3	4	5	6	7	8
NHHBUS	0.2285	0.3004	0.2663	0.4064	0.4458	0.2977	0.4242	0.4578
	[7.09]	[7.36]	[8.17]	[9.66]	[10.2]	[7.14]	[9.52]	[10.4]
NFTW	0.3068	0.3453	0.3286	0.3897	0.4035	0.2798	0.3372	0.4046
	[10.7]	[10.7]	[10.9]	[11.2]	[11.6]	[7.17]	[8.62]	[11.7]
LCEF	0.3048	0.3737	0.3387	0.4764	0.5156	0.5437	0.6644	0.5267
	[5.81]	[6.23]	[6.15]	[7.21]	[7.71]	[6.77]	[9.06]	[8.48]
HKML	0.6077	0.5194	0.5572	0.3871	0.3373	0.5190	0.3570	0.3235
	[34.7]	[16.1]	[45.8]	[15.3]	[12.0]	[15.5]	[11.9]	[11.3]
SELECT-IVITY	0.0089	0.0088	0.0091	0.0082	0.0078	0.0074	0.0070	0.0075
	[2.78]	[2.72]	[2.73]	[2.38]	[2.33]	[2.27]	[2.06]	[2.25]

	1	2	3	4	5	6	7	8
HKM_O	EX	EN	EX	EN	EN	EN	EN	EN
Ω	UN	UN	SC	SZ	SC	UN	SZ	SC
ρ	-	-	0.0000	0.2405	0.3314	-	0.2944	0.3887
	-	-	[-0.00]	[5.65]	[5.37]	-	[4.86]	[5.06]
L^*	- 528.7	-1355.5	- 628.1	-1486.1	-1463.5	-6886.0	-6989.3	-1461.8
ω_{OO}	1.5827	1.5562	1.5596	1.5855	1.6205	1.5687	1.6221	1.6326
ω_{22}	1.0077	1.0239	1.0132	1.1088	1.1595	1.0410	1.1634	1.1760
Function Evaln's	561	517	693	751	947	564	980	1085
Iterat.	17	16	20	22	26	17	27	27

Tests of alternative hypotheses with respect to the initial conditions $[y_{io}]$ and the error variance matrix are summarised in Table A2.6. These test statistics satisfy the chi-square distribution. We use the likelihood ratio test to identify the implications of the restrictions on the models.

Table A2.6 Likelihood Ratio Tests for Vehicle use Model Comparison

Test A: $2[L_2^\star - L_1^\star] + I \ln \omega_{oo} \sim \chi^2$ with	T degrees of freedom [T df.]
Test B: $2[L_6^\star - L_2^\star] + I \ln \det \omega_{22} \sim \chi^2$ with	$(T+1)(m-k_z)$ df.
Test C: $2[L_1^\star - L_3^\star] \sim \chi^2$ with	$T[T+1]/2 - 2$ df.
Test D: $2[L_2^\star - L_4^\star] \sim \chi^2$ with	$[T+1][T+2]/2 - 3$ df.
Test E: $2[L_5^\star - L_4^\star] \sim \chi^2$ with	2 df.
Test F: $2[L_2^\star - L_5^\star] \sim \chi^2$	$[T+1][T+2]/2 - 4$ df.
Test G: $2[L_7^\star - L_4^\star] + I \ln \det \omega_{22} \sim \chi^2$	$[T+1][m-k_z]$ df.
Test H: $2[L_8^\star - L_5^\star] + I \ln \det \omega_{22} \sim \chi^2$	$[T+1][m-k_z]$ df.

Test Number	Model Pair	LR	DF	χ^2
A	2,1	16545	4	reject
B	6,2	11100	5	reject
C	1,3	1198	8	reject
D	2,4	261	12	reject
E	5,4	45	2	reject
F	2,5	216	11	reject
G	7,4	11183	5	reject
H	8,5	194	5	reject

The preferred dynamic vehicle use model is Model 2 (Table A2.5) in which the initial conditions (HKM_o) are endogenous and the entire serial correlation matrix (j) is unrestricted as arbitrary positive definite. Model A imposes an exogeneity condition on HKM_o while maintaining an unrestricted Ω such that the elements take the form:

[a] correlation within initial conditions period:

$$\omega_{oo} = \sigma_\eta^2/[1\text{-}\kappa]^2 + \sigma^2/[1\text{-}\kappa]^2 + \sigma_\epsilon^2 \qquad [A2.1]$$

[b] correlation between initial conditions and observed wave t:

$$\omega_{ot} = \sigma_\eta^2/[1\text{-}\kappa] \qquad [A2.2]$$

[c] correlation within the observable period:

$$\omega_{st} = \sigma_\eta^2 + \sigma^2, \quad s=t \qquad [A2.3]$$

[d] correlation between observable periods:

$$\omega_{st} = \sigma_\eta^2, \quad s \neq t \qquad [A2.4]$$

The results in Table A2.5 represent the first known effort to estimate a dynamic vehicle use model in which explicit allowance is made for unobserved heterogeneity within the panel period and prior to the Panel (i.e. initial conditions), as well as true state dependence.

The findings suggest that for the subset of models 1 to 5 with no correlation assumed between the random effect and one time-invariant observed variable, that endogeneity of y_{io} and an arbitrary unrestricted [but positive definite] error variance matrix is the preferred assumption. The imposed correlational structure in models 4 and 5 when compared to model 2 is not an improvement on an arbitrary correlational form.

Table A2.7 Variables in the Dynamic Vehicle Use Model [1981-1985]

[$mths_v$ = the number of months in the last 12 months a vehicle has been in the households; vmhs = total vehicle months in the last 12 months. All dollar items are in 1981 dollars, adjusted by the consumer price index: 81 = 1.0, 82 = 1.102, 83= 1.234, 84 =1.309. To convert variables weighted by months held which give a per vehicle result to a fleet result, multiply by vmhs/12].

Variable Name	Derivation	Wave 1	Wave 2	Wave 3	Wave 4
Annual Hhld Km. [HKM] (km$*10^{-4}$)	Σveh.kms.$_v$	2.3994 [1.870]	2.3830 [1.798]	2.2703 [1.695]	2.3190 [1.703]
No. of full-time workers [NFTW]	Σ[no. empl. >20 hrs/wk]	1.3940 [0.940]	1.3590 [0.920]	1.3220 [0.920]	1.3140 [0.920]
No. of Hhld. Business Reg'd Vehicles[NHHBUS]		0.1890 [0.530]	0.2210 [0.580]	0.2440 [0.650]	0.2420 [0.630]
No. of Workers Employed in or Adjacent to City [CITYAR]		0.5330 [0.700]	0.4050 [0.630]	0.3910 [0.610]	0.3750 [0.580]
Age of Hhld Head [AGEHD]		43.300 [13.90]	44.410 [13.20]	44.940 [13.10]	45.780 [13.20]
Weighted Age per fleet veh. [AGEV] (years)	$\frac{\Sigma[ag_v * mths_v]}{vmhs}$	6.5400 [4.000]	6.6600 [4.100]	6.6900 [4.100]	6.6600 [4.300]
Household Life Cycle Stage:all kids > 11 yrs.		0.2350 [0.420]	0.2300 [0.420]	0.2380 [0.430]	0.2490 [0.430]

Table A2.8 Continued

Variable Name	Derivation	Wave 1	Wave 2	Wave 3	Wave 4
Weighted mass per fleet veh. [TWEIGH] (kg.)	$\Sigma[wt_v * mths_v]$	1074.0 [271]	1088.0 [265]	1084.0 [280]	1069.0 [299]
Annual Hhld Income minus annual veh. costs [DHINC] $((\$/10^5)/CPI)$		28.130 [15.70]	26.760 [15.30]	24.810 [14.60]	24.890 [14.20]
weighted unit recurrent maint. cost per vehicle [RMAINK]	$\frac{\Sigma[\text{recurr. maint.cost}]_v}{HKM}$	0.7570 [0.94]	0.9310 [2.00]	0.8370 [1.10]	0.7920 [1.10]
Weighted unit fuel cost per vehicle [PTCSK] ((c/km)/CPI)	$\Sigma[\text{unit fuel } cost_v * km_v]$	3.8750 [1.60]	3.6810 [1.40]	3.5170 [1.40]	3.5170 [1.50]
Weighted non-recurrent maint and repair cost per veh [NONRRC] $(\$p.a./10^3)/CPI)$	$\frac{\Sigma[\text{non-recurr } cost_v * mths_v]}{vmhs}$	0.2320 [0.30]	0.2230 [0.27]	0.2090 [0.30]	0.2030 [0.28]
Weighted asset value of fleet vehicles per vehicle [SELLP] $((\$/10^4)/CPI)$	$\Sigma[\text{sell price } * mths]_v/vmhs$	0.3510 [0.27]	0.3485 [0.30]	0.3418 [0.28]	0.3554 [0.31]

Table A2.8 Continued

Variable Name	Derivation	Wave 1	Wave 2	Wave 3	Wave 4
Selectivity correction	$\phi[^{-1}(\text{prob}_i)]$	3.835	3.783	3.972	3.742
[SC]	$/\text{Prob}_i$	[4.06]	[4.83]	[6.48]	[5.34]
Prob_i=probability of choosing ith fleetsize/body mix/type mix.					

Note: The mean values for the dynamic use and type choice models differ because [1] *other-business* registered vehicles are excluded from type choice; [2] zero vehicle households are *not in the type choice* model; [3] type choice is defined *on only the* holdings at the end of each wave, so that disposed vehicles are excluded. All vehicles held during part or all of the 12 month period are included in the calculation of annual household vehicle kilometres.

Model 2 is our preferred model. Of particular interest is the LR tests of Model 2 compared to Models 1 (Test A) and 4 (Test D). The restrictions on the serial covariance matrix (j) are given in equations [A2.1] - [A2.4]. Model 1 ignores the first column and first row of j because HKM_o is exogenous and the other components of the error matrix [A2.3] and [A2.4] are left as arbitrary positive definite. In Model 4 we constrain the j matrix to have elements given by equations [A2.1] - [A2.4]. That is, stationarity is imposed via equations [A2.1] and [a2.2]. The *additional parameter* in Model 4 (i.e. ρ) is a measure of the correlation between the standard deviation of the random effect η_q and the residual disturbance ν_{qt}. The LR test used to compare the unrestricted and restricted models both with endogenous initial conditions gives a value of 262.0 with 11 d.f. We can safely reject the null hypothesis (at the most stringent significance level) that the restricted model is no different to the unrestricted model. Interestingly the mean correlation between the error components for the restricted specification (i.e. between the random effect $\eta_h \sim$ NID(0, σ^2) and the residual disturbance $\nu_{ht} \sim$NID(0,σ^2)) is 0.24, significantly different from zero. We can also safely reject Model 1 over Model 2 on conventional levels of statistical significance. This suggests that an arbitrary unrestricted (but positive definite) serial covariance matrix within and between the initial conditions and the panel observations is a preferred assumption.

Except for the age of the head (AGEHD), all other variables are time varying. AGEHD enters as the age of the head at the beginning of wave 1; and is a proxy for the experience of the household in vehicle use (justified from our assessment of the data which indicates that households with older heads have more years of exposure to vehicle utilisation). The set of influences on vehicle use include the costs of owning and operating vehicles (PTCSK, RMAINK, NONRCC), the socio-economic composition of the household (AGEHD, DHINC, NFTW, LCEF), characteristics of vehicles (PRICE, NHHBUS), and lagged use. The endogenously specified lagged use parameter of 0.519 in Model B suggests that about one-half of the current level of vehicle use can be predicted by the previous period's use level and via the recursive nature of the dynamic use model system, by the use level in all previous periods. The income effect suggests that a 10% increase in real income ($\approx$ \$2500) will, ceteris paribus, lead to an increase in vehicle use of 0.70%.

The selectivity terms which further establish the link between vehicle use and vehicle choice are all statistically significant. The method (based on Lee (1983)) captures the relationship between the unobserved term in the conditional indirect utility function associated with the chosen vehicle(s) and the unobserved terms in the vehicle use model. The positive signs of the selectivity parameters signify a positive correlation between these unobserved terms. Unobserved factors that make the probability of choosing a vehicle more likely also have the effect of increasing the expected use of the vehicle.

Dynamic Choice Elasticities

A selection of elasticity estimates from the vehicle choice and use models are shown in Table A2.9. The vehicle choice elasticities are long run. The expectations index for variable g_{iht} is constructed as $g^*_{iht} = g_{iht} + \theta_{iht-1}$, where $\theta = 0.1$ by estimation. The use elasticities are short run in that vehicle portfolios are held fixed.

A generalised definition of the elasticity of vehicle choice with respect to the k^{th} exogenous variable, g^* obtained from the hierarchical nested logit model, $P_s \cdot P_{b|s} \cdot P_{m|sb}$, is:

$$\partial \log P_{aht} / \partial \log g^*_{aht} = \partial P_{aht} / \partial g^*_{aht} \cdot g^*_{aht} / P_{aht} \qquad [A2.7]$$

$$= g^*_{sbm,k} \kappa_k \, [\delta - P_{sbm}] \qquad [A2.8]$$

where $\delta = \Delta_{ss} \cdot \Delta_{bw} \cdot \Delta_{mz} \cdot 1/\lambda_{sb} + \Delta_{bw} \cdot \Delta_{mz} \cdot [1/\lambda_{sb} - 1/\tau_s].P_{m|sb} + \Delta_{mz} \cdot [\tau_s - 1].\tau_s \cdot P_{b|s} \cdot P_{m|sb}$. [A2.9]

and $\Delta_{ss} = 1$ if $s = 1$, otherwise $= 0$.

Thus we are able by the application of [A2.8] to derive direct and cross elasticities within and between levels of the hierarchical vehicle choice system. Elasticities can be obtained for each household using sample enumeration, with weighted aggregate elasticities calculated as probability weighted household-specific elasticities. The elasticities reported in Table A2.8 for type choice and fleet size are derived using (A2.8).

The type choice capital-cost elasticities tend to be lower than those found elsewhere in the literature. Capital cost is predicted to exert very little influence on vehicle choice, especially for one and two vehicle households. We found, however, that the capital cost elasticities increased significantly when the experience effects were omitted, suggesting that other studies may be suffering misspecification problems from the non-inclusion of these variables. The fuel cost elasticities broadly conform to those obtained in other studies. That these and the capital cost elasticities increase for larger fleet sizes may be attributed to the increased flexibility in type choice (mix) enjoyed by these households. One vehicle households are typically constrained to choosing a vehicle to meet overall family needs. Multiple vehicle households in contrast are able to tailor vehicles for specific household mobility tasks. The absolute vehicle cost burden is also greater for these households.

Table A2.8 Elasticity Estimates from the Dynamic Vehicle Type Choice and Use Models (Using Sample Enumeration)

Variable Description	Weighted Aggregate Elasticity Estimate
Type choice model	
capital cost of fleet:	
1 vehicle households	-0.032
2 vehicle households	-0.092
3+ vehicle households	-0.201
Annual fuel cost of fleet:	
1 vehicle households	-0.822
2 vehicle households	-1.063
3+ vehicle households	-1.478
Fleet Size Model	
Household income	
2 vehicle households	1.024
3+ vehicle households	1.181
Number of driver's licences	
1 vehicle households	2.965
2 vehicle households	3.658
3+ vehicle households	4.230
Number of full-time and part-time workers	
2 vehicle households	0.980
3+ vehicle households	1.117
Age of household head	
3+ vehicle households	1.434
Hierarchical Elasticities:	Mean
Fleet size choice with respect to capital cost of fleet:	
1 vehicle households	-0.003
2 vehicle households	-0.031
3+ vehicle households	-0.066

Fleet size choice with respect to annual fuel cost:	
1 vehicle households	- .146
2 vehicle households	- .291
3 vehicle households	- .407
Fleet size choice with respect to household income (in type choice only)	
1 vehicle households	0.046
2 vehicle households	0.076
3 vehicle households	0.550
Use model	
Unit fuel cost	-0.075
Household income net of operating cost	0.041
Unit maintenance cost	-0.039
Non-recurrent costs	0.026
Vehicle price	0.038
Lagged Vehicle Use	0.591

Fleet size elasticities are reported for exogenous variables from the body-mix and type-mix choice levels of the nested structure. The inclusive values have to be used in the calculations with both inclusive values entering the derivation of fleet size elasticities with respect to fleet capital cost, fuel cost, and household income associated with type choice; and only the body-mix inclusive value entering into the calculation for household income (associated with body mix), number of driver licences, number of workers, and age of the household head.

The elasticity of the probability of a multiple-vehicle fleet size with respect to household income is relatively elastic (1.02, 1.18 respectively for 2 and 3 vehicle fleets of private plus household business registered vehicles). This result is very plausible, and highlights the role of income in influencing fleet size in contrast to its relatively negligible effect on vehicle use (0.041). The inclusion of the additional income effect introduced via the type choice decision for 2-vehicle households is negligible, increasing the elasticity from 1.02 to 1.096; however for 3-vehicle households the change is quite strong, increasing from 1.18 to 1.73. Thus we can conclude that the level of vehicle ownership is positively associated with household income, with indications that the direct elasticity increases with the number of private plus household-business registered vehicles in the fleet, holding the number of *other-business* registered vehicles at a constant level.

The choice of vehicle type mix is much more sensitive to vehicle capital costs and vehicle fuel costs than is fleet size, with the elasticities being higher within a level than between a level of the nested structure. In all circumstances the absolute elasticities increase as the fleet size increases.

Turning to the vehicle use elasticities, it will be noted that these are lower than estimates to be found in the literature. Our methods, however, add a degree of sophistication which is absent from most other studies. The general view is that short run fuel elasticities, for instance, are between -0.05 and -2.00, with Australian evidence by Schou and Johnson (1980) of -0.08 using time series data. We expect the results to be at the lower end of the range once an allowance has bean made for state dependence and habit persistence (as also confirmed by Johnson and Hensher (1979) in a mode choice context). People in the short run are somewhat insensitive to fuel cost in relation to vehicle use.

Conclusions

The results in this Appendix are a product of an investigation into the development of a dynamic micro-econometric model of the household sector's joint demand for vehicle number, composition and use. We have emphasised an approach which is theoretically consistent, methodologically sound, computationally tractable and capable of application in a large number of policy and scenario planning contexts. The selection of the final set of influences in vehicle choice and use have been guided by economic theory in the first instance as well as the potential to obtain data on the influencing effects for application of the model system.

The extensions of static discrete/continuous choice models to a dynamic context (which is almost mandatory when the discrete choice involves consumer durables) confirms the important role of expectations and experiences in the overall explanation of choice. What we have available now is a detailed set of empirical models capable of providing guidance on a number of *what if....* questions about changes (or the lack of change) in financial tools (e.g. sales taxes on automobiles and fuel, cost of vehicle manufacture), vehicle technology (e.g. weight reduction by use of plastics, improved fuel consumption), passenger and load carrying capacity, and the socio-demographic composition of the population (e.g. household size, income, number of workers, life cycle and location of workplaces).

APPENDIX III DERIVATION OF THE GENERALISED PRICE ELASTICITY OF ENERGY DEMAND

For individual vehicles, define the identity:

$$\text{Total Energy Consumed (E)} = \sum_{v=1}^{V} VKM_v/FE_v;\quad v=1,...,V \text{ vehicles} \tag{1}$$

where VKM_v = annual vehicle kilometres of vehicle v and FE_v = fuel efficiency in litres per 100 kilometres achieved by the vth vehicle.

For vehicles grouped by vintage (to enable the application of group-level characteristics):

$$E = \sum_{g=1}^{G} VKM_g/FE_g, \text{ where } VKM_g \text{ and } FE_g \text{ are group means, } g=1,...,G \text{ groups.} \tag{2}$$

Multiply equation (2) by (VKM*V)/(VKM*V), where $VKM = \sum_{v=1}^{V} VKM_v/V$ = the average VKM driven per vehicle for the whole fleet, and define

$$FE = 1/\{\sum_{g=1}^{G} \frac{1}{FE_g} * \frac{VKM_g}{VKM} * \frac{V_g}{V}\} \tag{3}$$

where FE is a weighted harmonic mean of the efficiencies characterising each vintage group rather than an arithmetic mean. That is the average fuel efficiency of the entire vehicle population. Then:

$$E = \left\{\sum_{g=1}^{G} \frac{1}{FE_g} * \frac{VKM_g}{VKM} * \frac{V_g}{V}\right\} VKM*V \tag{4}$$

$$\text{i.e. } E = \frac{VKM}{FE} * V \tag{5}$$

Assume that VKM_v = f(real price of petrol: P_e, and other factors), then equation (5) becomes:

$$E = (VKM(P_e)/FE(P_e))*V(P_e) \tag{6}$$

Taking natural logs on both sides of equation (6) we get

$$\log E = \log VKM(P_e) - \log FE(P_e) + \log V(P_e) \tag{7}$$

Divide both sides of equation (7) by log P_e, and noting that the ratio of two logarithmic items is an elasticity, we get:

$$\epsilon_{e,p_e} = \epsilon_{vkm,p_e} - \epsilon_{fe,p_e} + \epsilon_{v,p_e} \qquad (8)$$

Since each of the behavioural elasticities on the RHS are negative, they are all summed to give the overall fuel price elasticity of demand for energy. QED

APPENDIX IV SUMMARY OF SELECTED FUEL-DEMAND ELASTICITIES

Table A5.1

Gasoline Demand Elasticity Estimates

Australia	Price Elasticity		Income Elasticity		Time-Span	Frequency	Region
	Short-run	Long-run	Short-run	Long-run			
Brain and Schuyers (1)	—0.11	—0.22	0.72	n.a.	N.R.-1974	A	N
Folie (2)	—0.04 to —0.38	—0.14 to —0.77	0.28 to 0.86	0.90 to 1.52	58Q3-74Q2	Q	S
Schou and Johnson (3)	—0.02 to —0.08	n.a.	0.63	n.a.	55-76	A	N
New Zealand							
Hughes (4)	—0.11	—0.14	0.57	0.79	69Q1-79Q4	Q	N
United States							
Data Resources, Inc. (5)	—0.07 to —0.14	—0.24 to —0.32	0.28 to 0.45	0.94 to 1.03	63Q1-73Q4	Q	S
Houthakker and Taylor (6)	—0.16	—0.45	n.a.	n.a.	20-41 & 46-61	A	N
Kraft and Rodekohr (7)	—0.20	—0.72	0.14	0.49	54-72	A	S
Nordhaus (8)	—0.22	—0.76	0.39	0.84	59-72	A	N
Phlips (9)	—0.11	—0.68	n.a.	1.34	29-41 & 46-67	A	N
Sweeney (10)	—0.12	—0.73	0.85	0.78	53-73	A	N
n.a. - not available, A - annual, Q - quarterly, N - national, S - state-level,							

(1) P. Brain, and G.S. Schuyers, *Energy and the Australian Economy*, Longman Cheshire, Melbourne, 1981.
(2) M. Folie, *op. cit.*
(3) K. Schou, L.W. Johnson, *op. cit.*
(4) W.R. Hughes, "Petrol Consumption in New Zealand 1969-79: Fixed and Time Varying Parameter Results", *New Zealand Economic Papers*, 14, 1980, pp. 28-42.
(5) Data Resources, Inc., *op. cit.*
(6) H.S. Houthakker, L.D. Taylor, *op. cit.*
(7) J. Kraft, and M. Rodekohr. "A Temporal Cross Section Specification of the Demand for Gasoline Using a Random Coefficient Regression Model", *Energy*, 5, 1980, pp. 1193-1202.
(8) W.D. Nordhaus, "The Demand for Energy. An International Perspective", in W.D. Nordhaus, ed, *Proceedings of the Workshop on Energy Demand: May 22-23 1975* International Institute for Applied Systems, Laxenburg, Austria, 1979
(9) L. Phlips, *op. cit.*
(10) J.L. Sweeney, "Effects of Federal Policies on Gasoline Consumption", *Resources and Energy*, 2, September 1979, pp. 3-26

Source: Donnelly (1982)

Table A5.2 Summary of Fuel Demand Models

AUTHOR (PERIOD) COUNTRY	ENDOGENOUS VARIABLE, MODEL, ESTIMATION METHOD	DATA	VARIABLES, ELASTICITIES PRICE	INCOME	OTHER VARIABLES	QUALITY OF ESTIMATION
LEHEERT (1960 - 1973, 1960 - 1974) GERMANY	fuel consumption in metric tons CE, lin and log, lin with KOYCK lag	annual	real producer prices of fuel, index of net industrial production 1960 - 1973: - 0.25 1960 - 1974: - 0.40	 1.33 1.11	lagged endogenous, temperature 0.36 0.04	 R^2=0.999 DW=2.111 R^2=0.997 DW=1.518
FLEMIG (1965 - 1979) GERMANY	volume of fuel (incl. Diesel) taxed, lin. model with variables as deviation from trend	quarterly data aggreg. from monthly season. adjusted data	real price index of fuel, real disposable income - 0.38	 0.27	none	R^2=0.55 DW=1.04
KRIEGSMANN (1960 - 1978) GERMANY	gasoline consumption on roads in CE, log-model, OLS	annual	real producer prices of fuel, real GDP, - 0.44	 1.90	none	R^2=0.935
FOTIADIS HUTZEL WIED - NEBBELING FRONIA (1962-1976) GERMANY	index of real expenditures for fuel, dynamic linear model, lag-distribut., OLS	annual	price index of fuels A: absolute B: related to total private consumpt. A: private consumpt. with lag-distribution B: real disposable income A: - 0.57 B: - 0.83	 1.20 0.86	A: change in expendit. for cars, lagged endogenous B: lagged endogenous	A: R^2=0.997 DW=1.97 B: R^2=0.995 DW=1.90
TEICHMANN (1973 - 1981) GERMANY	domestic sales of gasoline in metric tons, log-model, OLS	monthly data on gasoline sales season. adjusted, data for 4 cities in Germany (North-rhine Westphalia)	nominal or real prices for gasoline from ARAL, nominal or real per capita GDP - 0.29 to - 0.93	 1.03 to 3.65	none but separate estimation of cross elasticities, which are positive or negative	$R^2 \in (0.76, 0.88)$ $DW \in (1.15, 1.70)$
PROSKE (1966 - 1978) AUSTRIA	gasoline consumption static log-model	annual	real fuel price index, real GDP - 0.40	 1.50	none	not given
PUWEIN (1966 - 1980) AUSTRIA	gasoline consumption static log-model	seasonally adjusted quarterly	real prices of gasoline, income data not specified - 0.25	 1.30	fuel price relative to Germany (-0,56)	not given

AUTHOR (PERIOD) COUNTRY	ENDOGENOUS VARIABLE, MODEL, ESTIMATION METHOD	DATA	VARIABLES, ELASTICITIES PRICE	INCOME	OTHER VARIABLES	QUALITY OF ESTIMATION
HOUTHAKKER, TAYLOR, (1929 - 1964, without W.W.II) USA	real per capita expenditures for gasoline and oil, lin. state adjustment model, OLS	annual	real fuel price index, private per capita consumption expenditures not sign.	0.55	Dummy for period before W. W. II, lagged endogenous	R^2=0.998 DW=2.00
HOUTHAKKER, VERLEGER, SHEEHAN (1963-1972, 48 states) USA	gasoline consumption, logarithmic dynamic flow adjustment model, EC	seasonally adjusted quarterly	real price of gasoline, real personal per capita income - 0.08	0.303	lagged endogen.	R^2=0.929
VERLEGER SHEEHAN (II/1963 - IV/1972) USA	gasoline consumption, logarithmic flow adjustment model, EC	quarterly	real price of gasoline, disposable per capita income - 0.14	0.45	lagged endogenous	R^2=0.92
MEHTA, NARASIMHAM, SWAMY (I/1963 - IV/1973, DC - 48 states) USA)	private per capita consumption of gasoline, linear flow adjustment model with error component, EC	quarterly	real price of gasoline, real personal per capita income - 0.04	0.87	lagged endogenous	not given
REZA, SPIRO (I/1969 - III/76 USA	gasoline consumption, linear model, iterative purging of serial correlation	seasonally adjusted quarterly	A: real price of gasoline, B: real price of gasoline per km real disp. p. capita income - 0.21	0.60	lagged stock of vehicles, lagged weight of new cars, dummy for 73/74	R^2=0.98 DW=1.91
KWAST (1963 - 1977, 48 states + DC) USA	gasoline consumption logarithmic dynamic flow adjustment model, EC	annual	real fuel price, real personal income - 0.07	0.03	population, dummy for oil crisis, regional dummies lagged endogenous	R^2=0.99
BERZEG (1972/I - 1976/IV, DC - 48 states) USA	gasoline consumption logarithmic flow adjustment model with error component, ML, EC	quarterly	real price of gasoline, real personal income - 0.15	0.24	consumer price index, population, lagged endogenous	only t-values and standard errors are given

AUTHOR (PERIOD) COUNTRY	ENDOGENOUS VARIABLE, MODEL, ESTIMATION METHOD	DATA	VARIABLES, ELASTICITIES PRICE	INCOME	OTHER VARIABLES	QUALITY OF ESTIMATION
GREENE (1967 - 1977, 50 states + DC) USA	state highway gasoline consumption, BOX-COX-transformaformation, regional price and income coefficients GLS-variance component estimation	annual	state gasoline prices from 55 cities, real disposable income - 0.10 reg. range (0.00 to -0.20)	0.40 (0.30 to 0.40)	population (density, structure), urbanization, employment, stock of cars and trucks, regional price and income dummies	only t-values and standard errors are given
GAUDRY (1956 - 1982) CANADA (Quebec)	gross sales of gasoline BOX-COX-transformation, ML	monthly	real price of gasoline per kilometer, no income - 0.11	real retail sales 0.24	total of 43 independent variables for - prices - motor vehicles - activities, - infrastructure, - weather - other	R^2=0.987
TISHLER (1966 - 1978) ISRAEL	gasoline consumption, linear model, 3SLS	annual	real price of gasoline, private consumption - 0.25	0.88	stock of cars 0.34	R^2=0.998
OLDFIELD (1972 - 1978) GREAT BRITAIN	kilometers driven per car regist. logarithmic model, log. endogenous, lin. exogenous, OLS and BOX-JENKINS	monthly	real price of gasoline, A: real earnings B: GDP per capita A: - 0.12 B: - 0.10	 n.s. 0.70	variables describing - weather - unempl. - prices of pub. transp. - seas. dummies	R^2=0.95 DW=1.64 R^2=0.96 DW=1.79
TANNER (1965 - 1980) 19 countries	gasoline consumption per car, static logarithmic model, OLS	annual -	index of real gasoline prices, per capita GDP, results vary widely, averages are - 0.27	0.18	trend variable	not given
BALTAGI, GRIFFIN (1960 - 1978) 18 OECD countries	gasoline consumption per car, static log-model, OLS GLS and other dynamic models with KOYCK (1), polynominal (2) lags and different estimation techniques NERLOVE-type EC estimation	annual	real price of gasoline, real per capita income		stock of cars per capita	
		CANADA	- 0.36	0.39	-0.44	R^2=0.791
		USA	- 0.28	0.11	-0.96	R^2=0.453
		JAPAN	- 0.14	- 0.05	-0.56	R^2=0.999
		AUSTRIA	- 0.79	0.76	-0.52	R^2=0.680
		GERMANY	- 0.17	0.40	-0.22	R^2=0.492
		SWITZERL.	- 0.40	1.07	-0.62	R^2=0.923
		UK	- 0.06	0.56	-0.33	R^2=0.685
		FRANCE	- 0.20	1.14	-0.86	R^2=0.735
		ITALY	- 0.37	0.12	-0.36	R^2=0.978
		SPAIN	- 0.08	0.83	-0.10	R^2=0.967
		SWEDEN	- 0.62	0.71	0.04	R^2=0.478
		static	- 0.36	0.60	-0.62	R^2=0.834
		dynamic 1	- 0.17	0.16	-0.16	R^2=0.944
		dynamic 2	- 0.59	0.54	-0.66	R^2=0.830

Source: Blum et. al. (1989)

Table A5.3 Summaries of Gasoline Demand, Miles, and Miles-per-Gallon Models

	Price		Income		Data and	
	SR	LR	SR	LR	Model	References
Mean	−0.24	−0.65	0.51	1.42	Flow	McGillivray, 1976; Anmany,
Range	−0.11	−0.48	0.44	1.29	TS(y)	1976, Phlips, 1972, Fisheison, -
	to	to	to	to		1982, Schou & Johnson, 1979[a]
	−0.38	−0.76	0.58	1.54		
Mean	−0.19	−0.59	0.54	1.32	CSTS(y)	Kennedy, 1974; Pindyck, 1979;
Range	−0.03	−0.10	0.09	0.66	Flow	Rodekohr, 1979, Dewees, 1975;
	to	to	to	to		Kwast, 1980[b]
	−0.46	−1.61	0.85	1.94		
Mean	−0.12	−0.56	0.18	0.73	Flow (q) TS	Donnelly, 1982[c]
Range	−0.09	−0.38	0.09	0.54	& CSTS	
	to	to	to	to		
	−0.16	−1.03	0.25	0.86		
Mean	−0.08	−0.22	0.43	1.04	Flow (q)	Houthakker et al., 1974;
Range	−0.04	−0.05	0.28	0.94	CSTS	Verleger, 1975; Data
	to	to	to	to	lag 1 q	Resources, 1973; Mehta et al.,
	−0.14	−0.29	0.87	1.22		1978
Mean	−0.18	−0.38	0.56	1.16	Flow (q) TS	Hughes, 1980B; Folie, 1977
	−0.04	−0.14	0.28	0.79	lag 1 q	
	to	to	to	to		
	−0.38	−0.77	0.86	1.52		
Mean	−0.12	−0.61	0.29	1.48	Flow (m) TS	Hartmann et al., 1981; Uri,
	−0.11	−0.61	0.28	1.42		1980; Danielson & Agarwal,
	to	to	to	to		1976[d]
	−0.13	−0.61	0.30	1.55		
Mean	−0.13	−0.20	0.33	0.59	Stock-flow	Baas et al, 1982; Dewees et al.,
	−0.05	−0.12	0.10	0.50	(m, q, y)	1975; Dahl, 1982[e]
	to	to	to	to	CSTS, TS	
	−0.20	−0.26	0.63	0.84		
Mean	−0.25	−0.65	0.42	1.01	DL (m, y)	Houthakker & Taylor, 1970;
	−0.01	−0.22	0.22	0.57	TS, CSTS	Hein, 1969; Dewees et al.
	to	to	to	to		1975; Peleaz, 1981; Griffin,
	−0.52	−1.26	0.75	1.38		1979; Hughes, 1980A; Drollas,
						1984[f]
	(Price)		(Income)			
Mean	−0.35		0.45		Stock CSTS	Greene, 1979, 1980; Dewees
Range	−0.02		0.17			et al., 1975; Rodekohr, 1978,
	to		to			1979; Dahl, 1978; Burright &
	−1.05		0.83			Enns, 1975[g]
Mean	−0.26		0.46		Stock (y) TS	Dahl, 1978; Houthakker &
Range	−0.14		0.22			Taylor, 1970; Tishler, 1980
	to		to			
	−0.44		0.72			
Mean	−0.52		0.41		H (q, y)	Archibald & Gillingham, 1980,
Range	−0.22		0.29		CSTS	1981
	to		to			
	−0.77		0.56			

	Price		Income		Data and Model	References
Mean	−1.02		0.53		Stock (y)	Koshal & Bradfield, 1977;
Range	−0.70		0.33		CS	Stewart & Bennet, 1975;
	to		to			Wheaton, 1982; Adams et al.,
	−1.28		0.83			1974; Griffin, 1979; Drollas, 1984[h]
Mean	−0.41		0.41		Other Stock	Springer & Resek, 1981;
Range	−0.10		0.32		(m, q, y)	Springer, 1978; Greene, 1981;
	to		to		TS, CSTS	Hartmann, et al., 1981; Gallini,
	−0.75		0.47		CS	1983 Ostro & Naroff, 1980[i];
Mean	−0.56		0.84		Non-stock-	Ramsey et al., 1975; Mount &
Range	−0.17		0.36		flow (y) TS	Williams, 1981; Berzeg, 1982[j]
	to		to			
	−1.36		1.37			
Miles Traveled	(SR	LR	SR	LR)		
Means	−0.32	−0.55	0.26	0.60	Stock (q, y)	Dahl, 1979; Archibald &
Range	−0.10	−0.50	0.15	0.54	TS, CSTS, H,	Gillingham, 1981; Hill, 1978;
	to	to	to	to	CS	Burright & Enns, 1975; Chase,
	−0.50	−0.60	0.47	0.66		1974; Kouris, 1983; Fishelson,
						1982; Springer, 1978; Sweeney,
						1979; Wheaton, 1982[k]
Mean	−0.14	−0.33	0.78	1.44	Other stock	Springer & Resek, 1981; Reza
	−0.06	−0.33	0.60	1.44	(q) TS, CSTS	& Spiro, 1979
	to	to	to	to		
	−0.21	−0.33	0.97	1.44		
Mean	−0.18	−0.90	0.52	2.78	Flow (y) TS,	Pindyck, 1979; Cato et al.,
	0.0	0.0	0.06	0.66	CSTS	1976
	to	to	to	to		
	−0.36	−1.8	0.98	4.9		
Miles per Gallon						
Mean	0.17	0.57	−0.07	−0.21	Stock, Flow,	Archibald & Gillingham, 1981;
Range	0.06	0.32	−0.03	−0.21	Non-stock-	Wheaton, 1982; Pindyck,
	to	to	to	to	flow, DL,	1979; Kouris, 1983; Dahl,
	0.21	0.69	−0.08	−0.21	CSTS, TS,	1979; Burright & Enns,
					CS, H (y)	1975; Sweeney, 1979, Gallini,
						1983

Sourece: Dahl (1986)

[a]McGillivray (1976), Fishelson (1982), and Schou and Johnson (1979) are included under flow models because they include lagged endogenous and a stock variable but no income. Schou and Johnson's (1979) extremely low price elasticity has been omitted from the mean and range computations.

[b]Dewees (1975), with a positive but insignificant price elasticity, is not included in the computation of the mean price elasticity. Kwast (1980) with a very elastic long-run price elasticity of −1.59 and a low long-run income elasticity of 0.76 has been left out of the mean and range calculations.

[c]The lags on Donnelly (1982) are four quarters.

[d]The model by Danielson and Agarwal (1976) is left out of the mean calculations because its lagged endogenous variable has a 1-month lag, whereas the others have a 12-month lag. Their short- and long-run price elasticities are −0.16 and −0.26, whereas their short- and long-run income elasticities are 0.16 and 0.26. Hartmann's atypical estimates on data from 1975 to 1979 are excluded from the mean as well as the range computations.

[e]The long-run price elasticity of −0.98 in Dahl (1982) is eliminated from the mean and range calculations. It appears that given the large variation in the cross section of the data, long-run price elasticities are being captured.

[f]The means for each variable have been computed using only those studies that have a distributed lag on the given variable. The low-income elasticities of Hughes (1980A) of 0.01 in the short run and 0.07 in the long run have been left out of the mean and range computations.

[g]The random coefficient estimates of Rodekohr (1979) on OECD countries and the positive price elasticity of Kraft and Rodekohr (1978) on the U.S. Pacific are left out of the calculations of the means and ranges.

[h]Wheaton's (1982) income elasticity is not included in the computation. It appears that the price of autos, which is not of the expected sign and also is not highly significant, is not picking up the same adjustment as the vehicle variables in the other equation. Thus, this elasticity is similar to the long-run income elasticity from flow models. The dependent variable in Adams et al. (1974) and Griffin (1979) was gasoline per auto and they included auto weight as an independent variable. To make theirs more comparable to other studies, their auto term was taken to the right-hand side and combined with the auto per capita variable and their weight equation was substituted into their gasoline demand equation.

[i]The negative income elasticities of Hartmann et al. (1981) and Gallini (1983) are excluded from the elasticity computation.

[j]The positive price elasticity for Luxembourg from Mount and Williams (1981) has been left out of the mean and range calculations.

[k]The atypical price elasticities in Hill (1980) of 1.90 for households that did not move and −2.25 for households that did move, as well as price and income elasticities of Springer (1978) on quarterly state data are excluded. Wheaton (1982) on a strict cross section is considered long run. In Kouris (1983) and Fisheison (1982) the dependent variable is miles per autos. Their auto term has been taken to the left-hand side to make the studies more comparable. Their income elasticities are excluded from the means and range computations. Burright and Enns (1975) and Chase (1974) do not have income variables included.

[l]The long-run estimates come from the strict cross section of Wheaton (1982), the estimates for miles per gallon of new autos, and long-run flow models. If the atypically large long-run estimates of Pindyck (1979) and Gallini (1983) are included, the long-run price elasticity is 0.84

APPENDIX V AIRCRAFT CHARACTERISTICS: THE AUSTRALIAN FLEET 1986–1988

YEAR	ATYPE	FSIZE	SEATS	THOURS	AVUT	DIST	SPEED	LFPASWGT	LFALLWGT	SEATKMLT
1986	A300	4	230	10620	2655	903	607	73.8	61.9	18.7
1986	B767-200	5	211	12097	2419	946	622	68.8	53.8	21.5
1986	B727-200	25	144	74065	2963	1013	654	76.7	67.2	12.6
1986	B737-300	12	102	33329	2777	722	599	72.0	62.0	15 6
1986	DC9	9	92	27980	2806	650	577	78.6	69.8	13.7
1986	BAE146	2	75	6647	3340	808	576	73.5	62.4	13.1
1986	F28-4000	6	69	19862	3310	765	571	68.5	58.7	12.4
1986	F28-1000	7	55	14713	2102	573	588	67.2	59.3	12.4
1986	F27	27	48	60379	2101	308	323	65.8	63.0	17.8
1986	ARGOSY222	2	NA	2370	1185	679	306	NA	NA	NA
1986	ARGOSY101	1	NA	452	452	681	308	NA	NA	NA
1986	B727-100	1	NA	1340	1340	2653	770	NA	54.2	NA
1986	ALL	103	NA	264172	2541	667	544	NA	NA	NA
1987	A300	3	230	9982	2676	924	611	72.3	63.7	18 7
1987	B767-200	5	211	13874	2775	1001	630	71.4	56.3	21.5
1987	B727-200	23	144	73752	3050	1068	662	75.7	68.4	12.6
1987	B737-300	24	109	38470	2784	759	593	73.5	55.8	15.6
1987	B737-200	NA	102	14524	2916	726	596	72.5	60.8	15.6
1987	DC9	6	92	20394	2856	642	574	74.3	69.0	13.7
1987	BAE146	2	75	667[illegible]	3336	824	595	78.3	65 9	13.1
1987	F28-4000	6	69	20332	3389	773	573	66.2	58.9	12.4
1987	F28-3000	2	64	274	3914	804	569	68.7	67.3	12.4
1987	F28-1000	7	55	15643	2280	589	594	69.3	60.8	12.4
1987	F27	24	48	51248	2032	338	324	63.3	62 6	17.8
1987	ARGOSY222	2	NA	2586	1293	649	312	NA	NA	NA
1987	ARGOSY101	1	NA	522	522	649	312	NA	NA	NA
1987	B727-100	1	NA	852	852	2577	765	NA	53.3	NA
1987	ALL	106	NA	277200	2596	705	551	NA	NA	NA
1988	A300	3	230	7317	2439	834	591	77.5	69.8	18 7
1988	B767-200	5	211	15106	3021	910	614	72 3	58.3	21.5
1988	B727-200	23	144	70270	3055	1069	659	81 1	71.8	12.6
1988	B737-300	24	109	77620	3234	844	611	78.6	60.0	15.6
1988	DC9	6	92	15587	2598	631	565	77.2	71.0	13.7
1988	BAE146	2	75	7357	3679	816	564	75.8	64.2	13.1
1988	F28-4000	6	69	17659	2934	750	572	70.2	60.8	12.4
1988	F28-3000	2	64	6304	3152	794	571	70.8	68.5	12.4
1988	F28-1000	7	55	18147	2592	621	569	70.4	62.3	12.4
1988	F27	19	48	40237	1935	342	320	64.1	61 3	17.8
1988	F50	9	50	7903	2183	359	369	65.2	58.5	17.2
1988	ARGOSY222	2	NA	2850	1425	629	308	NA	NA	NA
1988	ARGOSY101	1	NA	600	600	631	308	NA	NA	NA
1988	B727-100	1	NA	1155	1155	2433	769	NA	53.1	NA
1988	ALL	110	NA	288112	2708	749	563	NA	NA	NA

YEAR	1985/6 to 1987/8
ATYPE	Aircraft type[a]
FSIZE	Fleet size[a]
SEATS	Seats per aircraft[a]
THOURS	Total hours flown on scheduled regular public transport services[a]
AVUT	Average Aircraft Utilisation represents the average hours flown by one aircraft over a year, expressed in kms/hour[a]
DIST	Number of kilometres an aircraft flies on scheduled regular public transport services divided by the total number of take-offs performed on such services, expressed in kms[a]
SPEED	Kilometres flown on scheduled regular public transport services divided by hours flown on scheduled regular public transport services, expressed in kms/hour[a]
LFPASWGT	Load factor for passengers, expressed as a percentage[b]
LFALLWGT	Load factor for passengers and cargo, expressed as a percentage[b]
SEATKMLT	Seat kilometres per litre[c]

Sources:

a	Transport and Communicaitons (1989): Air Transport Statistics, Domestic Airline Aircraft Utlisation 1985/6 to 1987/8
b	Transport and Communications, Avstats
c	Ansett Airlines for F27 & F50 (using Formula 1 below) and Greene (1989a) for others (using Formula 2 below)

Formula 1 - Used to Convert Kilograms per hour Fuel Burn into Seat Kilometres per Litre:

e.g. 680kg/hour to 17.8 seatkm/litre for the F27

680 kg/hour = .680 tonnes/hour

.680 tonnes/hour * 1261 = 857.48 litres/hour (where 1261 is the conversion factor of aviation turbine fuel from tonnes to litres)

857.48litres/hour = 0.37 km/litre (given average speed of 320kph)

0.37km/litre * 48 seats (number of seats available) = 17.8 seatkm/litre

Formula 2 - Used to Convert Seat Miles per U.S. Gallon to Seat Kilometres per Litre:

1 mile/gallon = .3518 km/litre

REFERENCES

Abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
AGPS	Australian Government Publishing Service
ARRDO	Australian Railway Research and Development Organisation
NIEIR	National Institute of Economic and Industry Research
OECD	Organisation for Economic Cooperation and Development
VFT	Very fast train

Agnew, W. G. 1988, *Future Personal Ground Transportation,* GMR-6419, General Motors Research Laboratories, Warren, Michigan.

Alson, J. A., Alder, J. M. & Baines, T. M. 1988, The motor vehicle emission characteristics and air quality impacts of methanol and compressed natural gas, Paper presented at the Symposium on Transportation Fuels in the 1990's and Beyond, Monterey, California, July.

ABARE 1988, Forecasts of road transport fuel consumption 1986–87 to 1999–2000, Internal working paper, ABARE, Canberra.

ABARE 1989, *Projections of Energy Demand and Supply Australia 1989–90 to 1990–2000,* ABARE, Canberra.

ABARE 1991, *Projections of Energy Demand and Supply — Australia 1990–91 to 2004–05, AGPS, Canberra.*

Australian Institute of Energy 1980, *Petroleum, Policies and People, Proceedings of the 2nd National Conference,* Australian Institute of Energy, Melbourne.

Australian Institute of Petroleum 1989, 'Product demand forecasts through to 1999', *Petroleum Gazette,* no. 3, pp. 2–24.

ARRDO 1981, *Energy and Railways: Summary Report,* ARRDO, Melbourne.

Blair, R. D., Kaserman, D. L. & Tepel, R. C. 1984, 'The impact of the improved mileage on gasoline consumption', Economic Inquiry, XXII, April, pp. 209–17.

Bland, B. H. 1984, *Effect of Fuel Price on Final Use and Travel Patterns,* Transport and Road Research Laboratory Report LR1114.

Blum, U. C. H., Foos, G. & Gaudry, M. J. I. 1988, 'Aggregate time series gasoline demand models: Review of the literature and new evidence for West Germany', *Transportation Research,* vol.22A, no. 2, March, pp. 75–88.

Boeing 1989, *Current Market Outlook,* Boeing Commercial Airplanes, Seattle, Washington.

Borsch-Supan, A. 1987, *Econometric Analysis of Discrete Choices, Lecture Notes in Economics and Mathematical Systems,* Springer-Verlag, Berlin.

Brain, R. 1982, A Spectral forecast of vehicle registrations in N.S.W. by age and category of vehicle, Paper presented to the Second Conference on Traffic, Energy and Emisssions, Joint SAE-A/ARRB Conference, Melbourne, May.

Bureau of Transport Economics 1986, *Consultative Forecasting Seminar 1985,* Australian Government Publishing Service, Canberra.

Bureau of Transport and Communications Economics 1988a, *Trends and Prospects for Australian International Air Transport,* Occasional Paper 88, Australian Government Publishing Service, Canberra.

Bureau of Transport and Communications Economics 1988b, *Forecasting Aircraft Movements at Major Australian Airports,* BTCE Occasional Paper 92, Australian Government Publishing Service, Canberra.

Bureau of Transport and Communication Economics 1989, *Freight Flows in Australian Transport Corridors,* BTCE Occasional Paper 98, Australian Government Publishing Service, Canberra.

Caddy, V. 1985, *The Development and Use of Energy Models in the Private Sector: An Example of Motor Gasoline Demand MOdelling in Energy Modelling in Australia,* Workshop Report no. 17, National Energy Research Development and Demonstration Program, Canberra, pp. 93–112.

Clark, O. 1989, New applications for natural gas: Cogeneration and transportation, Paper presented to the 1989 Energy Conference, Sydney, 8–9 August.

Clarke, D. 1989, Global oil markets to 2000, Paper presented at a seminar convened by the Australian Petroleum Exploration Association, Canberra, 24–5 October.

Cosgrove, D., Gargett, D. & Viney, P. 1989, Simple demand equations for the short-term forecasting of air passenger movements, Paper presented at the Annual Meeting of the Economic Society of Australia, Adelaide, July.

Dahl, C. A. 1982, 'Do gasoline demand elasticities vary?' *Land Economics,* vol. 58, no. 3, August, 373–81.

Dahl, C. A. 1986, 'Gasoline demand survey', *Energy Economics,* vol. 7, no. 1, pp. 67–82.

DeLuchi, M. A., Johnston, R. A. & Sperling, D. 1988, 'Transportation fuels and the greenhouse effect', *Transportation Research Record,* no. 1175, pp. 33–44.

De Jong, G. C. 1989, Some joint models of car ownership and car use, Unpublished PhD thesis, Department of Econometrics, University of Amsterdam.

Department of National Development and Energy 1983, *Forecasts of Energy Demand and Supply, Australia 1982–83 to 1991–92,* AGPS, Canberra.

Department of Primary Industries and Energy 1987, *Forecasts of Energy Demand and Supply Australia 1986–87 to 1999–2000,* AGPS, Canberra.

Department of Primary Industries and Energy 1988, *Energy 2000 — A National Energy Policy Paper,* AGPS, Canberra.

Department of Resources and Energy 1984, *Forecasts of Energy Demand and Supply Australia 1984–85 to 1993–94,* AGPS, Canberra.

Donnelly, W. A. 1983, 'The regional demand for petrol in Australia', *Economic Record,* vol. 58, no. 163, pp. 317–27.

Drollas, L. P. 1984, 'The demand for gasoline: Further evidence', *Energy Economics,* January, pp. 71–82.

Drollas, L. P. 1987, 'The demand for gasoline: A reply', *Energy Economics,* October.

Dubin, J. A. & McFadden, D. L. 1984, 'An econometric analysis of residential electric appliance holdings and consumption', *Econometrica,* vol. 52, no. 2, pp. 345–62.

Energy and Enviromental Analysis 1985, Documentation of the characteristics of technological improvements utilised in the TCSM, report prepared for Martin Marietta Energy Systems Inc., Oakridge, Tennessee, June.

Energy Authority of New South Wales 1986, *New South Wales Energy Demand Forecasts, 1985–2004,* Energy Authority of New South Wales, Sydney.

Energy Focus 1990, 'Gas powered buses to slash State Transit's fuel bill', *Energy Focus,* no. 23, February, p. 3.

Goodwin, P. B. 1987, 'Dynamic car ownership modelling', in Rhys, G. & Harbour, G. (eds.), *Modelling Vehicle Demand: Alternative Views,* University of Wales, Cardiff.

Goodwin, P. B. 1988, *Evidence on Car and Public Transport Demand Elasticities, 1980–1988,* Transport Studies Unit Paper 427 (revised), Transport Studies Unit, University of Oxford, Oxford.

Greene, D. L. 1982, 'State-level stock system model of gasoline demand' *Transportation Research Record,* no. 801, pp. 44–50.

Greene, D. L. 1984, 'A derived demand model of regional highway diesel fuel use', *Transportation Research,* vol. 18B, no. 1, pp. 43–61.

Greene, D. L. 1989a, Energy efficiency improvement potential of commercial aircraft to 2010, Report prepared by the Oak Ridge National Laboratory for the US Department of Energy, October.

Greene, D. L. 1989b, CAFE or PRICE?: An analysis of the effects of Federal fuel economy regulations and gasoline price on new car MPG, 1978–89, Report prepared by Oak Ridge National Laboratory for the US Department of Energy (contract DE-AC05-84OR21400), October.

Greene, D. L. 1989c, 'Motor fuel choice: An econometric analysis', *Transportation Research,* vol. 23A, no. 3, May, pp. 243–55.

Greene, D. L. & Hu, P. S. 1984, 'The influence of the price of gasoline on vehicle use in multivehicle households', *Transportation Research Record,* no. 988, pp. 19–24.

Greene, D. L. & Roberts, G. F. 1984, 'Fuel consumption for road transport in the USA — a comment', *Energy Economics,* vol. 6, no. 2, pp. 145–7.

Hatanaka, J. 1981, 'An efficient two-step estimator for the dynamic adjustment model with autocorrelated errors', *Journal of Econometrics,* pp. 199–220.

Hensher, D. A. 1980, 'The automobile and the future', *Transport Policy and Decision Making,* vol. 1, no. 4.

Hensher, D. A. 1982a, 'The automobile and the future', *Transport Policy and Decision Making,* vol. 2, no. 2.

Hensher, D. A. 1982b, 'The automobile and the future: Some issues', *Transport Policy and Decision Making,* vol. 2, no. 2, pp. 93–128.

Hensher, D. A. 1985, 'An econometric model of vehicle use in the household sector' *Transportation Research,* vol. 19B, no. 4, August, pp. 303–14.

Hensher, D. A. & Smith N. C. 1986, 'A structural model of the use of automobiles by households: A case study of urban Australia' *Transport Reviews,* vol. 6, no. 10, pp. 87–111.

Hensher, D. A., Milthorpe F. W., Smith, N. C. & Bodkin, N. 1986, 'A note on the specification and selection of automobile fuel consumption and fuel cost variables', *Proceedings 11th Australian Transport Research Forum, Darwin,* vol. 2, pp. 181–99.

Hensher, D. A. & Milthorpe, F.W. 1987, 'Selectivity correction in discrete continuous choice analysis: With empirical evidence for vehicle choice and use', *Regional Science and Urban Economics,* vol. 17, pp. 123–50.

Hensher, D. A., Gunn, H. F. & Brotchie, J. 1989, 'A method for investigating the passenger demand for high-speed rail, *14th Australasian Transport Research Forum Proceedings, Perth, July,* pp. 459–76.

Hensher, D. A., Smith, N. C., Milthorpe, F. W. & Barnard P.O. 1988, *Dimensions of Automobile Demand: A Longitudinal Study of Household Automobile Ownership and Use,* Transport Research Centre, School of Economic and Financial Studies, Macquarie University, Sydney.

International Energy Agency 1987, *Energy Conservation in IEA Countries,* OECD, Paris.

Irwin, N. A. & Johnson, W. F. 1990, The implications of long term climatic changes on transportation in Canada, Paper presented at the 69th Annual Meeting, Transportation Research Board, Washington D.C., January.

Lave, C. A. 1980, 'Automobile choice and its energy implications', *Transportation Research,* vol. 14A, nos 5–6, October-December.

Le Cornu, J. K. 1989, Greenhouse gas emissions from the production and use of alternative transport fuels, Paper presented at the Greenhouse and Energy Conference, held at Macquarie University, Sydney, December.

Lynch, T. 1990, Energy, environmental, and economic benefits of Florida's high speed rail and maglev systems proposals, Paper presented at the 69th Annual Meeting of the Transportation Research Board, Washington D.C., January.

Madden, G. C. 1988, An econometric model of Australia passenger automobile demand: A segmented markets approach, *Economic Analysis and Policy,* vol. 18, no. 1, March, pp. 53–69.

Mannering, F. L. & Train, K. 1985, Economic models of automobile demand, *Transportation Research,* vol. 19B, no. 4, August.

Marks, R. E. 1989a, *Australia Energy Policy and Conservation,* Working Paper no. 89–035, Australian Graduate School of Management.

Marks, R. E. 1989b, *Towards 2000: Australian Energy Policy and Conservation,* Working Paper no. 89–004, Australian Graduate School of Management.

Marks, R. E. & Swan P. L. 1989, Abatement, the global commons, and Australian road transport, Paper presented at the Greenhouse and Energy Conference, Macquarie University, Sydney, November.

McDonnell Douglas 1989, *Outlook for Commercial Aircraft 1988–2002,* McDonnell Douglas, Long Beach, California.

McElhaney, D. R. 1987, Past national forecasts: How well did we do? Paper presented at the 67th Annual Meeting, Transportation Research Board, Washington D.C., January.

Metcalf, J. B., ed. 1985, *Towards 2010 — An Ambit for Road Research,* Research Report ARR 133, Australian Road Research Board.

Millar, M., Vyas, A. & Saricks, C. 1985, 'Long-term outlook for transportation energy demand', *Transportation Research Record,* no. 1049, pp. 57–69.

Mintz, M. M., Singh, M. Vyas, A. & Johnson, L. 1987, 'Transportation energy outlook under conditions of persistently low petroleum prices', *Transportation Research Record,* no. 1155, pp. 56–68.

NIEIR 1989, *The Energy Working Party: Part Two,* NIEIR, Melbourne.

Nesbitt, K. 1989, 'Highway electrification: The implications of uncertainty', *Proceedings of the USA Transportation Research Forum,* vol. 4, no. 2, pp. 85–95.

Organisation for Economic Cooperation and Development 1989, *Global Climate Change — The Energy Dimenson: Part 2: World Energy Outlook to 2005,* Environment Committee Group on Energy and Environment, OECD, Paris.

Oum, T. H., Waters, W. G. & Yong, J. S. 1990, *A Survey of Recent Estimates of Price Elasticities of Demand for Transport,* Working Paper in Transportation, Infrastructure and Urban Development Department, World Bank, Washington D.C.

Saddler, H. 1981, *Energy in Australia: Politics and Economics,* George Allen & Unwin Australia, Sydney.

Saricks, C. L. 1990, Technological and policy options for mitigating greenhouse gas emissions from mobile sources, Paper presented at the 69th Annual Meeting, Transportation Research Board, Washington, D.C., January.

Sweeney, J. L. 1984, 'The response of energy demand to higher prices: What lessons have we learned? *American Economic Association Papers and Proceedings,* vol. 74, no. 2, May, pp. 31–7.

Train, K. 1986, *Qualitative Choice Analysis: Theory, Econometrics and an Application to Automobile Demand,* MIT Press, Cambridge, Massachusetts.

Train, K., McFadden, D. L. & Ben-Akiva, M. E. 1987, 'The demand for local telephone service: A fully discrete model for residential calling patterns and service choices', *Rand Journal of Economics,* vol. 18, no. 1, Spring, pp. 109–23.

Transportation Research Board 1988, *Outlook for Commercial Supersonic and Hypersonic Transport Aircraft,* Transportation Research Circular no. 333, Transportation Research Board, Washington, D.C.

Transportation Research Board 1988a, *Future Development of the U.S. Airport Network: Preliminary Report and Recommended Study Plan,* Transportation Research Board, Washington, D.C.

Transportation Research Board 1989, *Aviation Forecasting Methodology: A Special Workshop,* Transportation Research Circular no. 348, Transportation Research Board, Washington, D.C.

US Department of Energy 1989, *A Compendium of Options for Government Policy to Encourage Private Sector Responses to Potential Climate Change, Report to the Congress of the United States,* US Department of Energy, Washington, D.C.

US National Academy of Sciences 1979, *Alternative Energy Demand Futures to 2010,* National Academy of Sciences, Washington, D.C.

Vaes, T. 1982, *Forecasting Petrol Consumption,* Paper Q3, PTRC.

VFT Joint Venture 1989, *VFT — Focus for the Future: A Progress Report,* VFT Joint Venture, Canberra.

Wabe, J. S. 1987, 'The demand for gasoline: A comment on the cross section analysis of Drollas', *Energy Economics,* October.

Wheaton, W. C. 1982, 'The long-run structure of transportation gasoline demand', *Bell Journal of Economics,* vol. 13, no. 2, Autumn, pp. 439–54.

Zudak, L. S. & Koshal, R. K. 1982, 'Demand for gasoline and automobile characteristics', *International Journal of Transport Economics,* vol. 9, no. 3, December, pp. 321–9.

ABBREVIATIONS

ABARE	Australian Bureau of Agricultural and Resource Economics
ADO	Automotive diesel oil
AFC	Average fuel consumed per vehicle per year
AIP	Australian Institute of Petroleum
avtur	Aviation turbine fuel
ARRDO	Australian Railway Research and Development Organisation
BTCE	Bureau of Transport and Communications Economics
BTU	British thermal unit
CAFE	Corporate average fuel efficiency
CFC	Chlorinated fluorocarbons
CNG	Compressed natural gas
DFV	Dual-fuelled vehicle
FFV	Flexible-fuel vehicle
GJ	Gigajoule
GNP	Gross natural product
GDP	Gross domestic product
IMP	Econometric model of the University of Melbourne Institute of Applied Economic and Social Research
LPG	Liquefied petroleum gas
maglev	Magnetic levitation railway
MTRAIN	Train operation simulation program of the State Rail Authority of New South Wales
NIEIR	National Institute of Economic and Industry Research
OLS	Ordinary least squares regression
OPEC	Organisation of Petroleum Exporting Countries
SMPG	Seat-miles per gallon
SMVU	*Survey of Motor Vehicle Usage*
STA	State Transit Authority of New South Wales
SURE	Seemingly unrelated regression
3SLS	Three-stage least squares
TSLS	Two-step least squares regression
US	United States
VFT	Very fast train
VKT	Vehicle-kilometres travelled
XPT	State Rail Authority of New South Wales express passenger train