Greenhouse Gas Emissions and the Demand for Urban Passenger Transport: Design of the Overall Approach

Occasional Paper

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Bureau of Transport and Communications Economics
OCCASIONAL PAPER 108

GREENHOUSE GAS EMISSIONS AND THE DEMAND FOR URBAN PASSENGER TRANSPORT:

DESIGN OF THE OVERALL APPROACH

David A. Hensher

ISSN 1032-0539
ISBN 0 642 20012 2

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 in Australia by the Department of Transport and Communications

FOREWORD

The Prime Minister announced in his 21 December 1992 Statement on the Environment that the Bureau of Transport and Communications Economics (BTCE) will provide a comprehensive analysis of the range of possible measures for reducing greenhouse gases in the transport sector.

Working Paper 10 outlines the BTCE's proposed methodology for analysing measures to reduce emissions of greenhouse gases. The objective of the project is to identify least-cost combinations of policy instruments in the freight (including pipelines), urban passenger, non-urban passenger and international (bunkers) segments of the transport sector.

Emissions from the urban passenger segment are estimated to account for almost half of all carbon dioxide emissions in the Australian transport sector. Little behavioural information is available, however, to permit accurate assessment of responses by individuals or households to policy instruments designed to reduce emissions.

The BTCE has therefore commissioned the Institute of Transport Studies (ITS) at the University of Sydney to generate and analyse empirical data for six Australian capital cities. This Occasional Paper describes the approach proposed by ITS for the urban passenger segment.

The views expressed in this paper are those of the Institute of Transport Studies and should not be attributed to the Department of Transport and Communications or the BTCE. An earlier version of this paper was presented by Professor David Hensher at a BTCE seminar in Canberra on 14 October 1993.

Dr Leo Dobes
Research Manager

Bureau of Transport and Communications Economics
Canberra
December 1993

ACKNOWLEDGMENTS

The comments and contributions of Leo Dobes, Patricia Green, Franzi Poldy, Mark Dess (Victorian EPA) and the ITS project team are greatly appreciated. The ITS project team is David Hensher, Tom Golob (ITS-Irvine), Jordan Louviere (Utah University), Frank Milthorpe, Helen Battellino, William Zhu, Tim Raimond, Rhonda Daniels, Ajay Nayyar and Jianlin Xu. Discussions with Gordon Ewing (McGill University), Michael Florian (University of Montreal), Ken Gwilliam (The World Bank), Fred Mannering (University of Washington) and Jill Mannering (Boeing) have been invaluable.

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Global climate change and its consequences for global warming, whether naturally evolutionary or enhanced by human habitation, is recognised by many governments as a matter of significant concern to the future of the planet. National Governments in particular have recognised an obligation to improve their understanding of the agents which contribute to climate change in both positive and negative ways and to introduce policies through various instruments (e.g. pricing, regulation, prohibition, incentive schemes) designed to reduce the accumulation of harmful agents of global warming.

At the centre of the debate on climate change is the phenomenon called the *enhanced greenhouse effect*, which warms the earth's atmosphere and its surface beyond the temperature associated with the natural greenhouse gas effect. The mean temperature of the earth's surface is about 33°C warmer than it would be in the absence of natural greenhouse gases such as water vapour, carbon dioxide, methane, nitrous oxide, and ozone. In the absence of this natural greenhouse effect, the earth would be uninhabitable. Within the bounds of the long-term balance maintained between the solar energy entering the atmosphere and energy leaving it, interactions among the earth's atmosphere, snow and ice, oceans, biota and land cause variations in global and local climate change (US. Congress 1991, Figure 1).

Although there is a substantial amount of scientific uncertainty about the climatic system's eventual response to greenhouse warming, associated with the accumulation of human activities which have generated substantial increases in the atmospheric concentrations of carbon dioxide, methane and nitrous oxides in particular, the balance of current opinion is that global warming will occur. There is strong disagreement however as to the timing, magnitude and regional patterns of climate change. The limited scientific "evidence" from modelling, observation and sensitivity analyses suggest that the sensitivity of global mean surface temperature to a doubling of the atmospheric concentration of carbon dioxide is in the range of 1.5 to 4.5°C (Houghton et al. 1992).

Despite the uncertainty and disagreement in the scientific community, the greenhouse effect and its *potential* consequences for global warming and global climate change has captured the attention of the public, the media and governments of many nations. It is with this background of uncertainty and perceived importance that the Rio Conference and its precedents have arisen. Prior to Rio there were six significant meetings:

February 1979: First World Climate Conference, Washington DC which established the world climate program, *October 1985* (Villach, Austria): Assessment Conference on the Role of Carbon Dioxide and Radiatively-Active Constituents in Climate Variation and Associated Impacts,

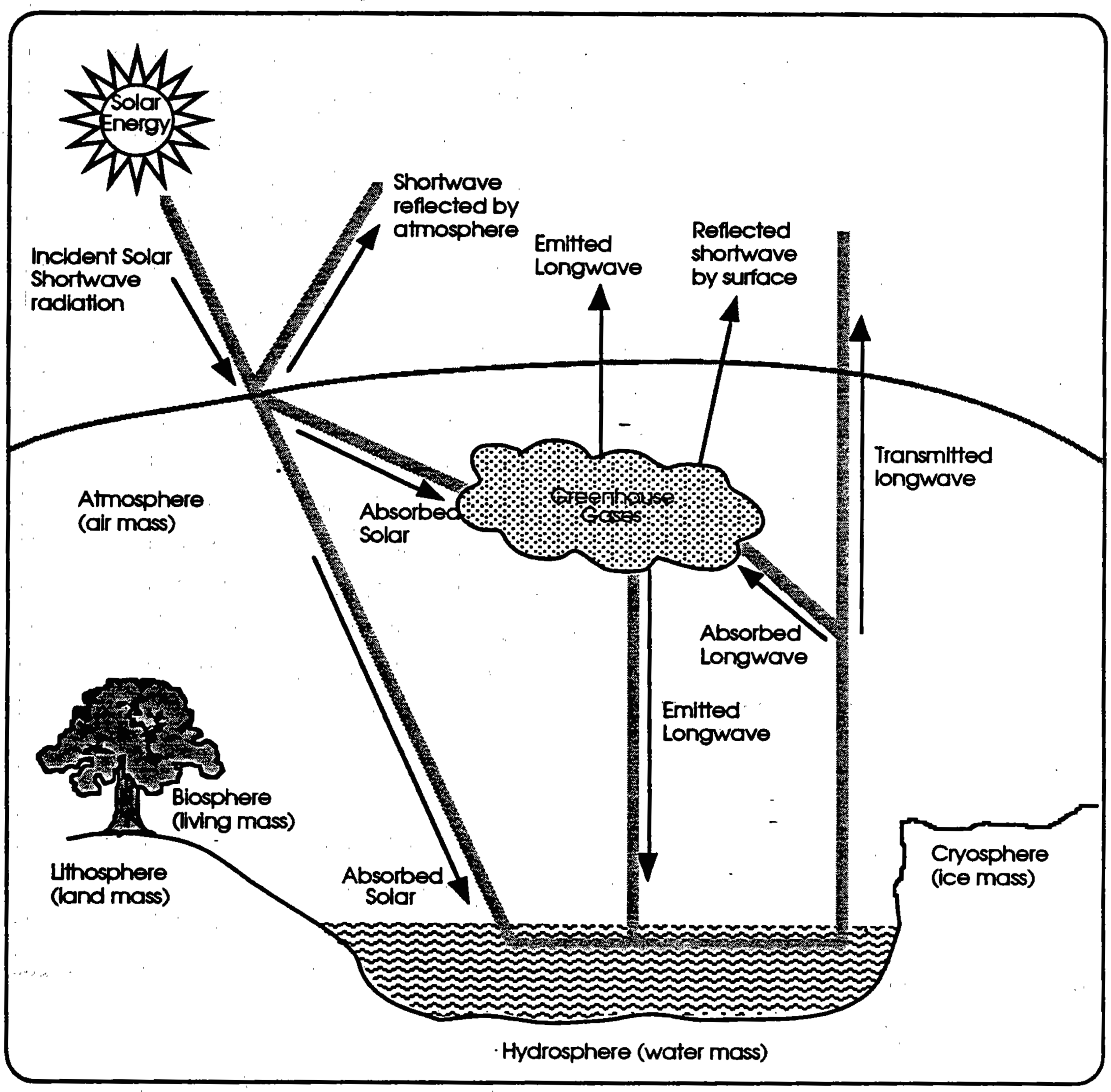
September 1987 (Villach, Austria): The Effects of Future Climatic Changes on the World's Bio Climatic Regions and their Management Implications,

November 1987 (Bellagio, Italy): Priorities for Future Management - A New Policy Agenda,

June 1988 (Toronto, Canada): the Changing Atmosphere: Implications for Global Security, and

November 1989 (Noordwijk, Netherlands): Ministerial Conference on Atmospheric Pollution and Climate Change.

Figure 1. The Essential Components of the Greenhouse Effect



The November 1987 meeting in Italy led to recommendations that greenhouse gas emissions be limited and adaptation measures be adopted. The Toronto meeting was the major political watershed, attended by 48 nations. It called for a comprehensive international framework convention and a 20-percent reduction in carbon dioxide releases from fossil fuels by 2005. The Inter governmental Panel on Climate Change (IPCC) was created in November 1988 by the World Meteorological Organisation (WMO) and the United Nations Environment Program (UNEP). The Noordwijk Conference in 1989 produced a Ministerial declaration which recognised the need to stabilise the emissions of carbon dioxide and some other greenhouse gases, while ensuring sustainable development of the world economy. A caveat was included that developing countries will need to be assisted financially and technically.

These resolutions were the key to securing the cooperation of developing countries and in establishing an obligation by industrialised nations to take the lead in reducing emissions and to compensate the developing countries for any diminished economic growth that might ensue from actions which might stabilise or reduce emissions. The United Nations Conference on Environment and Development, convened in Rio de Janeiro (Brazil) in June 1992. The *First Assessment Report* prepared by the IPCC obtained a United Nations General Assembly approved Resolution 45/212 establishing the Intergovernmental Negotiating Committee for a framework convention on climate change, to be supported by WMO and UNEP. Resolution 45/212 directed the Intergovernmental Negotiating Committee to prepare an effective framework convention on climate change, to be ready for the Rio Conference.

The Rio Climate Change Convention, signed by 154 nations in June 1992, is a framework document, containing a process of adopting future amendments and protocols (which may in the future be legally binding). The ultimate objective of the Convention (Article 2) "is to achieve ... stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system ... within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner" (United Nations 1992).

At the heart of the Convention is Article 4 on commitments. The most important provisions under the Commitments entered into by Australia include the preparation of national inventories of greenhouse gas sources and sinks and national programs to address climate change, and to cooperate in preparing for adaptation to the impacts of climate change. Australia has committed itself (under Subparagraph 4.2(a)) to "... adopt national policies and take corresponding measures, by limiting its anthropogenic emissions of greenhouse gases and protecting and enhancing its greenhouse gas sinks and reservoirs". Under subparagraph 4.2(b) Australia has committed itself to provide detailed information on its policies and measures, including the projected effect on its net emissions of such policies and measures for the period up to the end of the decade "...with the aim of returning individually or jointly to their 1990 levels of these anthropogenic emissions of carbon dioxide and other greenhouse gases not controlled by the Montreal Protocol".

In supporting the Rio Convention, the Australian Government (with the support of the States) has embarked on a major assessment of alternative strategies to achieve stabilisation of carbon dioxide emissions to 1990 levels by the year 2000, and to establish policies which will carry Australia well beyond the year 2000 in its commitment to improve atmospheric quality.

A major contributor to enhanced greenhouse gas emissions (GGEs) is urban passenger transport, particularly the automobile. The major source of GGEs is carbon dioxide (CO_2), exhaled by people, cars, power plants, and anything else that uses oxygen to burn up fuel. Other important sources are nitrous oxide (N_2O), carbon monoxide (CO), non-methane organic compounds (NMOC's), methane (CH_4) and nitrogen oxides (NOx) and chlurofluoro-hydrocarbons (CFC's). Although CFC's are small in quantity they are so powerful that a car with a CFC-charged air conditioner is believed to contribute more to the enhanced greenhouse effect from loss of its refrigerant than from all the carbon dioxide emitted throughout the car's lifetime. CFC's however are being phased out because of their effect on stratospheric ozone and hence on ultraviolet radiation reaching the earth. CFC replacements (and leakage between now and when they are phased out) could still have a significant global warming effect. However, the main greenhouse gas of concern to future transport policy is CO_2, the inevitable combustion product of carbon-based fuel such as petroleum, natural gas or coal. In most developed countries the emissions from the use of automobiles alone (including emissions from feed stock recovery, processing and distribution, and from vehicle manufacture) have constituted up to 30 percent of the total CO_2 emissions from the use of all fossil fuels (Deluchi 1991, 1993).

The GGE project awarded to ITS (Sydney) is part of a more comprehensive study being undertaken by the Bureau of Transport and Communications Economics (BTCE) on determining the least cost combinations of measures to reduce enhanced greenhouse gas emissions for the entire Australian passenger and freight transport sector. The ITS study seeks to identify the relationship between greenhouse gas emission reductions and alternative passenger transport-related strategies, packaged individually or in combination. The emphasis is on *urban* passenger transport, although the impact of a large number of strategies spillover to non-urban travel activity (e.g. improvements in automobile technology, fuel charges and taxes). The incremental net cost associated with each strategy is identified, together with an assessment of the constraints that must be considered in any implementation strategy. The BTCE study is a major Australian contribution to the *Road From Rio*, in accordance with the goals and objectives of the National Greenhouse Response Strategy (Commonwealth of Australia, 1992).

The objective of this report (which embodies tasks 1 and 2 of the study) is to outline the method and the empirical approach we propose to develop to evaluate the impact on enhanced GGE reductions of a range of strategies designed to influence travel behaviour, including the possibility of alternative fuelled automobiles and more environmentally-friendly fossil-fuelled vehicles. The report is organised as follows. We begin with a statement of the way that transport-related policies may help to reduce enhanced greenhouse gas emissions, notably CO_2. We define the dimensions in which the outputs need to be presented so that appropriate statements can be made on the cost effectiveness of alternative instruments of policy. The set of identified and testable policies are used to guide the design of the entire study.

With an output-oriented philosophy in place, we then overview the major elements of the entire study, followed by the details of each major component. These include:

- the specification of the set of behavioural models centred on vehicle choice, travel choice and location choice, which provide the quantitative capability for evaluating traveller response to the agreed set of testable instruments

- the data requirements and their source as the empirical base for model estimation for six mainland capital cities

- procedures and data required to enable forecasts up to the year 2015 for a base strategy in each year (i.e. 'do nothing') and alternative strategies on a five-year increment with the implications of fast tracking selective policies

- the translation of traveller responses (e.g. changes in annual vehicle kilometres, changes in the annual number of trips by purpose, and vehicle substitution) into equivalent GGE changes, and

- the development and implementation of the ITS-BTCE strategy simulator to provide a desktop capability for evaluating the net economic cost of alternative mixes of instruments designed to reduce GGEs and in achieving the targets agreed under the Rio Convention.

The report concludes with a statement on the design of a reporting and documentation strategy to ensure that all the resources acquired under this project are accessible by future users of the strategy simulator, who will have the need from time to time to update the data bases, the models and the software.

2. OPPORTUNITIES TO REDUCE GREENHOUSE GAS EMISSIONS IN THE URBAN PASSENGER TRANSPORT SECTOR

It is conservatively estimated that 48 percent of carbon dioxide emissions from the domestic transport sector in Australia (1987-88) are attributable to the *use* of passenger vehicles (cars, buses and trains) in *urban* areas (Evans 1992). The great bulk, 96 percent, is associated with the automobile. If we take the 30 percent figure for the contribution of the automobile to total CO_2 emissions from the use of all fossil fuels (Deluchi 1991, 1993), then 14.4% of all CO_2 emissions are directly attributable to *urban* automobile use. The interest in the current study centres on changes in GGEs associated with changes in various policy instruments, documented below. This study concentrates on GGEs, primarily CO_2 together with CH_4, N_2O, CO, NO_x and NMOC. These last 5 emissions are expressed as equivalent CO_2 GGEs through a knowledge of *global warming potentials* (GWP's) (Deluchi 1991). We do not consider *local air pollution*. This is a topic in another study in progress (Hensher et al. 1993) and separately by the BTCE.

Identifying an expansive set of policy instruments for assessment is a critical first step. This will also guide the formulation of testable hypotheses and model specification as well as data requirements. It is convenient to *group* the potential instruments into a number of classes to signify the extent of impact within the transport market. The impact of some policy instruments designed to achieve change within the urban passenger transport sector will spillover to the non-urban passenger transport sector (e.g. a carbon tax), and hence achieve greater GGE reductions than might a policy instrument contained to urban activity (e.g. ride sharing). This makes for potentially more attractive instruments than those limited to urban activity, although it should not dismiss a mix of aspatial and spatial strategies. Although the primary focus is on strategies to reduce enhanced GGEs, many of the strategies contribute to the achievement of the broader goals of urban management and the performance of urban areas. A major product of this study will be a strategy simulator as a decision support system capable of evaluating a very broad set of urban transport strategies, some of which might have no significant impact on GGE reductions, but which may have a substantial impact on other urban goals.

There are two primary sets of classes designed to capture the full impact of instruments imposed on urban activity: (i) spatial vs aspatial specificity and (ii) urban vs spillover impacts beyond the urban area. Potentially interesting policy instruments within each of the four combinations are presented in Table 1. For example, regulations designed to change engine technology or fuel source have an impact on all contexts of vehicle use, are aspatial and have spillover benefits to non-urban activity. Congestion pricing within an urban area is spatially specific and has no (direct) spillover effects on non-urban activity (i.e. it is a contained urban

Table 1. Targeted Instruments and Main Class Impact

Potential Instruments to Evaluate	spatial (sp) vs aspatial (asp)	impact beyond urban area (√)
Congestion pricing (Mix of Charges and Taxes)	sp	
Parking charges (primarily CBD, regional centres)	sp	
Parking rationing/restrictions in CBD	sp	
Toll road charges	sp	
Restrictive automobile access to locations (CBD)	sp	
Sales tax on new autos (skewed and elimination)	asp	√
Vehicle registration charges (by age, weight, fuel)	asp	√
Company car provision and use	asp	√
Maximum age of vehicles in the vehicle park	asp	√
Carbon tax (linked to alternative fuels) *	asp	√
Fuel excise by fuel type: change and exemptions*	asp	√
Tradeable permits	asp	√
Fee-based compulsory emissions checks	asp	√
Price rebates/discounts on alternative fuelled vehs	asp	√
Govt purchase and scrap high emitters	asp	√
Alternative fuels - electric vehicles *	asp	√
Alternative fuels - LPG *	asp	√
Alternative fuels - CNG *	asp	√
Alternative fuels - diesehol *	asp	√
Reformulated petrol *	asp	√
Automobile engine/transmission technology *	asp	√
Automobile vehicle design (weight, drag) *	asp	√
On-board IVHS equipment	asp	√
Education on cold starts/hot soaks etc.	asp	√
Urban form and density (physical planning)	sp	
Urban form and density (housing codes))	sp	
Ride sharing and employer incentives	sp	
Telecommuting	sp	√
Compressed work week (time use)	asp	√
Non-motorised options - bicycle, walk	sp	
New public transport - light rail	sp	
New public transport - bus priority systems	sp	
Public transport - park-n-ride/kiss-n-ride	sp	
Existing public transport - fares policies	sp	
Existing public transport - levels of service	sp	

Instruments starred (*) are associated with parameters of automobiles, fuel, vehicle operating conditions and environmental conditions. The literature on automobile emissions (e.g. Guensler 1993) suggests that the following parameters are the major influences on emission rates. A set of equations have to be obtained which express CO_2 per kilometre as a parameterised function of each of the parameters in the table below.

Table 1 cont'd.

Vehicle Parameters	Fuel Parameters
Automobile class (weight, engine size, cc. etc)	Fuel type
Vintage	Oxygen content
Accumulated kilometres	Fuel volatility
Fuel delivery (e.g. carbureted or fuel injected)	Sulfur content
Emission control system	Benzine content
Onboard computer control system	Olefin and aromatic content
Control system tampering	Lead and metals content
Inspection and maintenance history	Trace sulfur effects on catalyst efficiency
Vehicle Operating Conditions	**Vehicle Operating Environment**
Stop-start driving	Altitude
Cold or hot start mode	Humidity
Average vehicle speed	Ambient temperature
Modal activities that cause enrichment	Diurnal temperature sweep
Load (e.g. air conditioning, towing, heavy load on board)	Road grade
Influence of driver behaviour	

policy). Aspatial instruments are much easier to evaluate than spatial instruments because the latter require much more information on an individual's current spatial context in which a particular instrument requires evaluation. Within each class there are instruments which are market-based, regulatory, standards, planning and infrastructure initiatives, involve institutional change, and which are centred on the dissemination of better information through education and other media. Some instruments are not well-suited to an assessment via a formal set of behavioural choice models (e.g. education), although we can attempt to identify, qualitatively, strategies which might aid in community acceptance of particular policies.

The identification of a set of instruments worthy of investigation requires careful translation into a set of explicit explanatory effects captured in a set of behavioural models which emphasise consumer choice of vehicles, travel activity and location of residence and workplace. Some of the impacts produce, in aggregate, changes in the density of urban activity. The change in the level of an explanatory variable captures the impact of each instrument on travel and locational behaviour (including choice of vehicle technology) which is then translated into emission changes and hence greenhouse impact. In the next section we outline the set of behavioural models required to evaluate the impact of the set of instruments on vehicle emissions and hence GGEs. To assist the selection of a testable set of instruments, we first review the extensive literature on travel and locational behaviour.

The extant literature on travel behaviour provides a limited amount of evidence on the impact of particular instruments in changing travel behaviour. While some broad conclusions can be stated (see below), there are often some spatially-specific considerations which can have a strong influence on behavioural response and hence the success of particular instruments.

Furthermore, any inferences are complicated by a general lack of assessment of the system-wide impacts of particular policies, especially policies which involve instruments not currently observed in real markets (e.g. congestion pricing). The system-wide impacts will be closely examined in the current study. For example, any incentive scheme to encourage a compressed work week in order to reduce the levels of traffic congestion on each weekday should, from an energy and emissions perspective, identify the use made of the time while not at work. On the non-work day it is possible that extra non-work travel occurs, which may be by car, compared to public transport use for the commuting trip. It may be a shorter or longer trip length depending on the nature of the non-work activity. Anecdotal evidence suggests that if a Monday or a Friday is part of the extended non-work period, then trip length by car may increase substantially. Furthermore increased leisure time tends to increase the demand for less fuel efficient vehicles such as 4WD and light commercial vehicles. The net effect on emissions could be an increase rather than a decrease in CO_2. We have to take this ambiguity into account and attempt to accommodate the system wide response through an appropriate specification of the set of behavioural choice models.

A time-differentiated congestion charge, for example, may not assist in reducing GGEs if the substitution between time of day of travel (i.e. peak spreading) changes travel speeds *throughout the day* in an adverse way. We might be better off containing the congestion during a limited period of time if a uniform congestion charge regime is not acceptable. Now that congestion pricing is technologically feasible (Hau 1992), the emphasis has to be placed on studies designed to understand the response of drivers to congestion pricing in the peak period, *and* at all times of the day. What fraction of users will shift their travel to off-peak times? To what extent will time-sensitive drivers be attracted to a less-congested road? What fraction of individuals will opt for ride-sharing or public transport, and how will this vary by income level and other equity-based criteria? What will be the degree of emissions reduction (if any) brought about by congestion pricing? The evidence is currently not available (Poole 1992).

The issue of technological "solutions" versus behavioural/market-based "solutions" pervades the literature on policies to achieve noticeable reductions in GGEs contributed by the automobile (e.g. Martin and Michaelis 1992, Small 1991). There is a substantial body of literature which supports the technological "fix": although difficult to achieve any form of change concomitant with reducing greenhouse gas emissions, it appears easier to achieve progress via an initial stimulation of technology (Hensher et al. 1992). Consumers will respond if the price is right and there are enough incentives. As societies pursue greater mobility, the idea of sustainable mobility centred around clean-fuelled automobiles becomes even more attractive: *"the desire for personal mobility seems to be unstoppable"* (Lave 1992).

Market forces have had a substantial impact on the shape and density of our metropolitan areas, with a very strong trend towards suburbanisation of workplaces, self-employment and highly variable work hours and work days (Brotchie 1991, Hensher 1993, Giuliano and Small 1993). With a trend towards a diminishing number of travel corridors of sufficient density over reasonable time periods of each day to justify rail-based public transport (be they light or heavy rail systems), the move away from monocentric to policentric urban activity reinforces the mobility benefits of the automobile (Giuliano and Small 1991). Reversal of this trend will be difficult but not impossible (Newman et al. 1993). Under this evolving scenario the future of bus-based public transport appears better than rail. Bus priority systems such as those introduced in Curitaba (Brazil) and Ottawa (Canada) can contribute much more to accommodating mobility needs in the growing number of corridors where the somewhat lower densities of movement rule out rail systems (Hensher and Waters 1993, Rutherford 1989). Together with the physical zoning of urban activity type and density codes, Curitaba and Ottawa have encouraged the linear development of medium to high density residential activity around a bus priority system, without the need to build the more expensive rail systems. The support for rail systems however is very strong, promoted by a belief that the permanence of public transport systems is an essential element of a physical planning approach to the production of better cities. 'Light rail and heavy politics' might best describe the current debate. Newman and his colleagues promote the physical planning paradigm as a major dimension of the urban reform process centred on "... the transition to a more compact, transit-oriented city which is more vital, sustainable, equitable and lively" (Newman *et al.* 1993).

In an unpublished manuscript, Sperling (1993) outlines an alternative 'suburbanisation' paradigm centred on clean-fuel automobiles in which he describes an optimistic yet achievable chronology of some of the key events along a potential pathway to sustainability up to the year 2010. In 1996 revenue-neutral rebate programs that tax polluting vehicles and provide rebates to clean vehicles should be introduced, giving substantial reductions to the cost of an electric vehicle ($US4,000). In 1998 tradeable greenhouse gas emission standards are adopted for all cars and light trucks followed closely by a more sophisticated air pollutant and greenhouse gas emission trading program for automobile manufacturers and fuel suppliers. By the end of the century, developers build a new town and purchase 20,000 very small neighbourhood electric cars, to be given free with the purchase of a home. Streets are specifically designed for neighbourhood cars. In the early years of the new century (up to 2003) the key automobile manufacturers offer 8 free days of car rentals each year for 4 years with every new purchase of an electric vehicle. A number of major local government areas ban all full size vehicles from 9am to 4pm in selected neighbourhoods. Speed limits of 35 kph are set on many streets. In the year 2003 the first fuel-cell bus enters commercial operation. The first mass-produced fuel-cell cars come on stream in 2008. In 2010 construction begins on the first solar hydrogen energy farm to supply fuel-cell vehicles.

The importance of an objective assessment of alternative paradigms of efficient, effective and ecologically sustainable transport strategies is critical to the acceptance and hence success of the current study. We are reminded however of the conclusion by Small (1991) who, in evaluating what might happen rather that what should happen in terms of the type of adjustment that our societies will make to diminish the potential adverse environmental impacts of transportation activities, concludes that *"People need not and will not choose solutions that reverse the trends toward increased mobility via personal vehicles"*.

2.1 Technological vs Behavioural "Fixes": The Real Challenge

In a comprehensive examination of the contribution made by transportation and land use measures to achieving the air pollution emission reduction targets of the 1991 Air Quality Management Plan in the Los Angeles Basin, Bae (1993) concludes that the measures aimed at reducing vehicle kilometres of travel have only a modest impact on reducing air pollution. The measures included alternative work schedules, mode shift strategies, and growth management. Technological solutions to the automobile emission problem were found to be much more important. Bae suggests that more transit use, ridesharing and telecommuting are *not* needed to achieve clean air objectives. They may, however, be desirable for other urban management objectives, although their success to date in altering travel behaviour has been somewhat limited (see Hensher et al. 1992, Hensher 1993, Lave 1992, Golob 1993). Although these arguments relate to air quality, the implications translate readily to greenhouse gases, because the basis of the evidence is an assessment of how individuals respond behaviourally to these various instruments. The adjustments in vehicle kilometres travelled by the automobile, in particular, is the key to reductions in enhanced greenhouse gas emissions.

There is a very simple phenomenon at work - as a society accumulates greater wealth, the desire for personal mobility and the ability to afford it grows. The automobile is then the preferred form of transportation (Small 1991). *Sustainable automobility* is now seen by many as the most viable "solution" to the greenhouse (and air quality) debate. Some commentators, however, often cite the European wisdom of the recent past in encouraging use of public transport through massive investment in highly subsidised heavy and light rail systems as an alternative strategy. The USA attempted this strategy, but was overrun by the substantially higher growth in wealth which stimulated and enabled automobility earlier than other countries (although the incentives through physical planning to use public transport essentially disappeared as investment in roads took over). The viability of public transport is now under threat from the automobile in Western Europe. Most Western European nations, over the period 1965-87, have experienced, a 3-to-1 ratio in the growth of automobiles per capita compared to the USA. The tough anti-auto policies in Europe have been overwhelmed by a far stronger force - the growth of personal income (Lave 1992). Although the link between automobile ***ownership*** and wealth is some indication of the demand for the *use* of automobiles (i.e. mobility), the critical issue in the current study is the extent and pattern of automobile use, especially in urban time and space where congested traffic environments prevail and where there may be ecologically sustainable opportunities for public transport.

For the period 1965-87, vehicle kilometres travelled per person increased in Europe 154 percent compared to 69 percent in the USA. This translates into an average of 13,000 kms per annum in 1987 in Europe and 15,900 kms in the USA for the same period. Indeed, if the number of trips on lower quality roads in Europe is higher than in the USA., then in recognising the impact on emission rates of the parameters distinguishing vehicles, fuel, operating conditions, and the operating environment (Table 1), the emissions per kilometre of travel by car are likely to be higher than in the US for the same manufacturer-specified fuel consumption levels.

Efforts internationally to "lure" auto users back to urban public transport, especially during the peak periods, have not met with any significant success. The predominant instruments have been subsidised fares, more modern and air conditioned vehicles, increased reliability and schedule frequency, free and secure parking at interchanges, and advertising campaigns. At best we can say that the long-term decline in patronage may be showing some signs of being slowed down and possibly halted, but there is no evidence of any noticeable reversal. What has been absent in the strategy to revive public transport has been any effort to make the automobile less attractive. Making a currently inferior product more attractive in the absence of making a superior good less attractive is never going to secure significant changes in behaviour (Hensher 1993). Throwing money at a relatively inferior form of mobility is no remedy.

One challenge is to identify public transport options which can assist the reversal of the current widespread trends, if such trends are deemed to be socially undesirable. Analysts have called for congestion pricing of urban automobile travel. Efficient pricing alone however is unlikely to produce a socially optimal investment outcome. What is required is a study framework which can evaluate the social benefits and costs of a large number of urban strategies including those directed by physical planning instruments, which have the capability of influencing the density and structure of urban areas. If we are able to assume that the preference functions of the current generation are sufficiently rich in their capability of evaluating alternative futures which include non-marginal changes in urban activity profiles (e.g. moving to a medium density living environment and a greater use of public transport compared to a low density living environment and a car-orientation), then we can identify socially optimal investments which are not heavily conditioned on incremental-creep determined by the current status quo.

At the same time that some planners are searching for viable public transport solutions, the automobile is becoming more energy efficient. Given the high correlation between fuel consumption and emissions of greenhouse (and noxious) gases (0.85 or better), the relative emissions benefits of a public transport "solution" are dissipating rapidly. The arguments in terms of traffic congestion and stress then become predominant in the debate on the future of public transport. Using the evidence on efforts to reduce local air pollution (which gives us good clues on behavioural responses to accommodate reductions in GGEs), if we take a city such as Los Angeles with a reputation as being one of the most polluted in the Western world (predominantly smog), automobile emission controls introduced in the last 10 years have resulted in significant *reductions* in reactive organic gases (18.2% from 1987 to 1991), 20.6% for nitrogen oxides and 45.7% for carbon monoxide. There has been much progress through major improvements in vehicle technology through tougher regulations. The downward trend is *not observed* for pollutants little caused by automobiles. Ozone (O_3) is the critical pollution problem in Los Angeles, being 2.7 times the federal standard. The real challenge may be to achieve *sustainable transport* through the *civilisation of automobility*. This civilisation includes continuing improvement in the fuel efficiency and de-polluting impacts of automobiles as well as the application of pricing and planning instruments to ensure that the full social costs of automobile use as well as opportunities for land use and public transport options are revealed. There is a great deal that can be achieved with fossil-fuelled automobiles through technological improvements to the engine, the transmission system, and the overall design of the vehicle. This study updates the technological options identified under the manufacturer's product plan and a maximum technology scenario reported in Hensher et al. (1992) and NELA (1991).

2.2 Changing the Spatial and Temporal Dimension of Work Activity

If we revisit the sixties and the seventies we will observe the rigidity of working hours, the predominance of full-time employment, the one worker household and the requirement to have employees physically located at their place of employment. This was pre-fax, pre-mobile phones, pre-desktop computers, and pre-electronic mail. We will also observe the very dominating role of central business districts in the supply of jobs. In combination with relatively low personal incomes, location and labour market practices worked well to assist the case for substantial public transport service (especially rail-based in the larger urban areas). Throughout the eighties and beyond, information technology combined with a *new order* in the employment market produced a new set of opportunities and constraints. At the same time personal incomes were increasing substantially.

Attitudes and opportunities to work changed, commencing with the increased participation of women in the work force. Initially we observed a significant growth in female employment on a part time basis and subsequently on a full time basis as child care facilities improved, as economic necessity became even more real, in part attributed to higher rates of divorce and loss of employment of the main bread winner, and as employers changed their attitudes about the commitment and contribution of women in the workforce. The opportunities for more leisure worked alongside a substantial increase in the wealth of households (aided significantly by the growth in multiple-worker households), with each reinforcing the need for the other, especially as leisure activities diversified substantially, especially in the overseas holiday market.

No longer was it necessary in all work activities to be physically located at the main employment location. With the support of labour unions, alternative work schedules were introduced giving greater scope for both extending the actual hours that a business was "open" as well as offering more scope for worker preferences in defining the hours per day, the days per week and the location of work activity. Although it is very early days in the full cycle of work time and space opportunities, the increased flexibility may work against the future of public transport, especially public transport which requires a relatively dense corridor of movement activity in order to be economically and environmentally sustainable. At the same time that work practices are loosening up, and more and more jobs are being suburbanised in part due to firms (i.e. jobs) following people, the radially biased high density public transport corridors are losing their growth opportunities (even though preserving in many instances their patronage).

Telecommuting, compressed work weeks, and flexible working hours are all evolving employment options. Telecommuting involves working from a remote office site which is typically the employee's home, although in the future satellite 'telework' centres near or in residential areas, fully equipped with appropriate telecommunications equipment and services, can serve employees of single or multiple firms, co-located on the basis of geography rather than business function (US DOT 1993). It is a specialised although growing activity in some countries, notably the USA (Urban Transportation Monitor, July 9, 1993). 7.6 million people in the USA are estimated to telecommute, typically spending 1 or 2 days per week working from home. They rely increasingly on computers and advanced telephone services to communicate with their regular office. One-third of the telecommuters are contract employees. The opportunity to telecommute will be determined by both the desire of the potential telecommuter, the policy of their employer and especially the attitude of immediate bosses. Telecommuting is currently an experiential issue - it is not known well enough for enough individuals to make a well-informed judgement about its prospects (Mannering 1993). It raises important questions about jobs-family balance and the social and personal benefits of degrees of spatial separation.

The implications for greenhouse gas emissions are ambiguous and need careful assessment (Pendyala et al. 1991, Nilles 1991). The ambiguity is in part due to the relationship between commuting and non-commuting travel activity, the interrelationships between activities of household members, especially but not exclusively workers, and the suburbanisation of workplaces (which may open up opportunities for deeper suburbanisation of residential location given the phenomenon of time budgeting). To take a very real and rich example, a two-worker household with children at different schools:

> Currently one worker has a multi-purpose city commute of 20 kilometres one-way, dropping off a child at school en route to the regular work place. The other worker has a part-time job within 4 kilometres from home, uses a bus and starts at 10 am., finishing at 1 pm. The other child is driven to a local bus stop to catch a school bus (the trip is 12 kilometres one way). Suppose the full-time employee opts for a 4-day working week, taking every Friday off and working 10 hours each day. They no longer take the child to school because they leave too early and get home too late. The first child now catches a local bus 5 days per week. The commute to the city now has a lower auto occupancy for much of the trip. On the day off the amount of driving is less but the number of trips (hence cold and hot starts) is double that of the commute, even though total kilometres have reduced a little. The part-time worker takes the car for the 3 hours on the other worker's day off, instead of using the bus. The opportunity to telecommute for two days for the full time worker subsequently is used to justify a residential location change further from the city, which increases vehicle kilometres per trip but reduces the number of commuting kilometres for this person. The part-time worker however has a longer commute and now requires a second car. The children have to be driven to school.

There is a lot of activity substitution occurring, with some of the change being emission-friendly, while other changes are emission-unfriendly. This example illustrates the response possibilities which need to be accounted for in determining the net impact of changing the spatial and temporal opportunities for work activities.

2.3 Jobs-Housing Balance and Land Use

A particularly important feature of the debate on the role of the daily commute is the jobs-housing balance. It has often been claimed that if we can balance jobs and housing spatially that commuting times can be reduced, automobile kilometres (vkm's) reduced and emission levels improved. Jobs-housing balance vehicle kilometre targets have been suggested as a way of reducing emission levels of transport modes. The success of directed action (on growth management) seems unlikely; rather spontaneous location adjustments due to firms decentralising to gain access to growing suburban labour pools (i.e. *jobs follow people*) is consistent with observed trends (Brotchie 1991, Gordon et al. 1989).

Other considerations affecting location choice and ipso facto commuting times such as high job turnover, high residential relocation costs, and employment heterogeneity in multi-worker households have been suggested as reasons why households seek accessibility to an array of possible future jobs rather than just to their current employment. If this is true, when combined with the growing importance of non-work trips, residential amenity and the location of the better schools, the current debate on "excess" commuting (e.g. Small and Song 1992) requires cautious interpretation. Excess commuting is the commuting cost above the lowest possible average commuting cost consistent with the geographical distributions of work and residential sites. Given the (inadequate) current pricing regimes, even if jobs and housing appeared to be in balance, there would be substantial inter-area travel as people take advantage of low priced mobility.

In the current study we allow for the possibility of residential and workplace location change, but assume that the supply of housing and jobs is not a constraint on the opportunity to relocate. Changes in density (e.g. population density) as an exogenous shock may be tested. The current study primarily looks at the first-order direct impacts of strategies on households. More desirable, albeit complex, equilibrating procedures designed to endogenously represent possible urban form changes over time are briefly discussed in Section 3.1.3 in order to place the current approach in perspective.

2.4 Conventional and Alternative Fuels

There is a great deal that can still be done with conventional automobile fuels to make them significantly cleaner, while recognising some of the inherent environmental benefits of non-fossil fuels. Such a strategy must be accompanied by a policy designed to ensure that owners of automobiles maintain them to the highest standard required to ensure that the full environmental benefits of improved oil-based fuels are achieved. Owners of automobiles, especially older vehicles, could assist in emission reductions by improving their maintenance program. Directed incentives to this effect may be required. Small (1991) views the alternative fuels strategy as more technological than behavioural; this has important implications for the way we investigate consumer demand for alternative-fuelled vehicles.

In addition to the enormous potential to *clean-up* conventional automotive fuels, alternative fuels worthy of consideration are compressed natural gas (CNG), liquefied petroleum gas (LPG), electricity for electric vehicles, and diesel. Although the primary purpose of our study is to identify the GGE implications of policies which impact on behaviour *within* the transport sector, the BTCE will have to take into account the *full fuel cycle* of GGE impacts. Electric vehicles, for example, are most likely to derive their electricity from predominantly coal-based electricity generation. Such fuels used in electricity generation give rise to some 40 percent of carbon dioxide emissions in providing some 19% of final energy (ESD 1991). Since coal releases higher carbon dioxide emissions per unit energy than petroleum fuels, this is compounded by substantial energy conversion and distribution losses in the electricity power system. Thus assuming a continuing domination of coal-fired systems in Australia, electrically-powered transport will need to achieve very high energy efficiency and high passenger loadings to have a noticeable impact on GGEs. In our study, we will identify the potential for electric vehicle penetration into the market on the assumption of no supply constraint, and calculate the net GGE cost of substitution from conventional fuels directly attributable to transport use (ignoring the emission implications of fuel generation and distribution). The net economic costs of GGE reductions may be higher than those we calculate in our partial equilibrium approach.

Hence, we might reject electric vehicles in the context of GGEs because of the full fuel cycle implications. If we accept the international evidence that electric cars are likely to raise costs by more than $US0.013 per vehicle kilometre, the amount up to which an individual will support policies for internalising the costs of air pollution (Small 1991), then they are of doubtful attractiveness as a widespread strategy for even reducing air pollution. Furthermore, if we accept Nordhaus's analysis of greenhouse gases (Nordhaus 1991) which suggests that the efficient package of policies to achieve the GGE reduction targets would have a marginal cost of $US0.13 per kilogram of carbon removed, then if the 10 kilometres of travel by electric vehicles does not give value to users in excess of their current costs by $US0.13 for every kilogram of carbon they produce, it is unlikely to be an efficient instrument for change. Indeed, higher costs above this amount have in the past produced technological changes in the form of downsizing and more fuel efficient automobiles, but little if any impact on the total use of passenger vehicles. These issues will be investigated in some detail in the current study.

2.5 Pricing, Charges and Taxes

It is generally recognised that a lot more can be achieved through pricing to improve the efficiency of transport systems. The historical under-pricing of both urban public transport and automobile use has made it very difficult, politically, for governments to redress the distortions of the past in recognition of the opportunity that pricing instruments have in externalising the environmental costs of transport mobility. In this study we evaluate a large number of pricing instruments (Table 1). Although some of them may not be introduced for political or administrative reasons, it is nevertheless important to identify their potential contribution or lack of significant contribution in reducing GGEs.

Incrementally, society is adjusting to a new regime of pricing incentives, such as tolls on private urban roads, which in the longer run should make it "relatively easier" to introduce widespread congestion pricing. An important feature of a strategy to achieve 'pricing acceptability' is to use the revenue to compensate travellers. Support for any pricing concept will be much higher when it is presented as a complete financial package with explicit proposals for using revenues (Jones 1991). Any package should explicitly recognise that in return for a user charge and the inconvenience to those who change behaviour to avoid such a charge, individuals and society receive benefits in the form of less traffic congestion (savings in time and operating costs), *and* the benefits from the use of the revenues. Where the new revenue replaces inefficient taxes (e.g. a vehicle sales tax) and/or facilitates attractive expenditures that are currently foregone through lack of funds (e.g. improved public transport and/or improved roads), the appeal to self-interested individuals and through them, the government, should be clear. We ignore the implications this might have on who collects the revenue (i.e. Federal vs State governments) and the ensuing debate on apportionment.

Small (1992) investigated a large number of revenue-using strategies with the objective of compensation and salient appeal to important political groups. It is important to recognise that the individuals who benefit from congestion relief and revenue uses do not necessarily coincide with those who pay the fees or who suffer inconvenience in order to avoid them. A financial package which accommodates specific objectives about the equity effects of the overall package is essential in gaining acceptability. In our empirical study we need to design alternative pricing packages and identify the distributional implications within the sampled population. This is a very important point:

> *a pricing strategy, to be acceptable, should be packaged to compensate for financial and distributional consequences. The stated choice experiments designed to elicit the impact of pricing regimes should evaluate alternative financial packages, and not isolated pricing options.*

The revenues from a congestion pricing strategy are likely to be so large (Goodwin et al. 1991) that for the first time there will be sufficient *annual* funds to offset negative impacts, promote social goals and obtain political support from interest groups (Small 1992). For automobiles only (i.e. excluding trucks and buses), approximately $4bn per annum for all of Australia's capital cities would be available (based on a congestion charge of 10 cents per kilometre). (Note that users of the M4 motorway in Sydney pay a toll of $1.50, which given an average distance travelled on the M4 of 15 km, equates to 10 cents/km). This approximates the current annual receipts from fuel and sales taxes on automobiles. Current taxes are not strictly charges (indeed the debate on the incidence of a charge and a tax is still open). Consequently the case for earmarking back to the transportation sector must allow for some amount of revenue from congestion pricing going into consolidated revenue where there is substitution with current sales and fuel taxes. A congestion pricing scheme is unlikely to be revenue neutral from a government point of view, in respect of lost revenue from reduced sales and fuel taxes. Some of the revenue can substitute for general taxes now used to pay for transport services, but a significant visible amount should be allocated as monetary reimbursement to travellers as a whole and to the provision of new transport services. The Federal and State governments will be no worse off; they almost certainly will be better off. Small (1992) proposes that two-thirds be earmarked to transportation users and facilities.

There are many possible compensating strategies within a pricing/financial package. We will evaluate each of the following measures individually and in combinations (either within the stated choice experiment or by a separate set of questions):

(i) *employee general commuting allowances*: a fixed amount per month for each employee (independent of mode or time of commute), designed to give money back directly to commuters while giving them the flexibility to avoid some or all of the higher use costs by shifting modes, routes or times of day. Those who do not shift are compensated, those who do shift are also compensated, and those in the past who did not contribute to traffic congestion by commuting at other times of the day and/or used public transport are rewarded for their prior travel behaviour. This general commuting allowance (not tax deductible *or* taxable) is incentive compatible with the objectives of congestion pricing (including offsetting any regressive aspects of congestion charges). It should be administered by the employer. The measure could be widened to include priced parking currently supplied for free by an employer (or as part of a salary package).

(ii) *Replace part or all of the fuel tax component returned to the transport sector*: as a more economically efficient method of raising revenue, we might see an amount of the revenue raised by congestion pricing being explicitly earmarked for *urban* transport programs. As a regressive tax, a fuel tax is partially replaced by a somewhat more progressive explicit user charge. The Federal government component of fuel tax which is retained can remain revenue neutral. We must recognise that a sizeable quantity of the fuel tax derives from non-urban travel which is not under congested traffic conditions, and so this component of fuel tax returned to the States should be separated out. The allocation of these funds to particular transport projects has to be carefully thought through. Some should go to new road infrastructure with the recognition however that the existing capacity can now handle road traffic better than before, thus lessening the pressures for new road investment. The case for high-occupancy vehicle (HOV) lanes may also be lessened, further increasing the effective road capacity already in place. Some funds might be expected to go into improving public transport. If the case is greatest for bus priority systems, then the opportunity to "add one lane" rather than "take one lane" from the existing road system becomes financially feasible and politically much more attractive (Hensher and Waters 1993). Johnson (1993) has recently thrown doubt on the emissions benefits of HOV lanes. An investigation of HOV lanes in Sacramento for vehicle occupancies of 2 or more persons suggests that the introduction of such lanes leads to an increase in vehicle kilometres. The revenue from any pricing strategy should be tied to projects with acceptable benefit-cost ratios to avoid the risk of a "cash-cow" or "pet-projects" mentality. This will destroy the value of congestion pricing.

(iii) *Transport-related improvements to the urban commercial centres*: congestion pricing increases the cost of access to commercial areas. There are a number of transport-related improvements to facilities and services which can "compensate" the local business community in ways which secures their support for congestion pricing. These include pedestrian walkways and plazas, landscaping, improved public transport interchanges, especially for bus systems, and loading bay offsets for urban goods deliveries and collections. Local Chambers of Commerce are influential and important interest groups to be accommodated.

There are other pricing strategies which can complement congestion pricing. Some of them are likely to be easier to introduce, given their aspatial nature. The major contenders include: new vehicle sales tax reductions and/or elimination, designed to increase the scrappage rate of high emitter vehicles; a higher sales tax on new relatively high GGE emitting automobiles (which are not necessarily the luxury class vehicles currently subject to higher sales tax than other vehicles); changes in registration fees either by a skewed registration charge designed to favour low polluting vehicles or a smaller fee to compensate for increased use-related charges; differential duties on imported vehicles designed to encourage overseas manufacturers to import low emitting vehicles.

Like congestion pricing, a financial package is an attractive way of securing individual and political support. Part of the package might be *marketable emission permits* (MEP) and an *emissions equity fund*. Two issues are of great importance: (i) the recognition that high polluting vehicles may be owned and operated by low income households, and (ii) that an ongoing incentive scheme is necessary to attract consumers into the low-polluting vehicle market segment. MEP's provide a mechanism for securing low-emitting loyalty through credits to low emission vehicles. These credits should accrue to both consumers and manufacturers. There are many ways in which the consumer's credits can be used - discounts on repairs and maintenance, and a vehicle buy-back plan with attractive financial guarantees. Some revenue raised from fuel taxes can be allocated to an emission's equity fund to assist individuals whose vehicles have non-complying emission levels. The options could include a major overhaul of the vehicles emission system or the scrapping of the vehicle. Indeed a manufacturer could offer marketable credits to an owner of a high emitting vehicle in return for having the vehicle scrapped. The credits could be at least equivalent to the trade-in price for the vehicle as part of a purchase deal on a low emitting vehicle. In both instances some financial assistance may be required on equity grounds. This is analogous to child allowance for households with a taxable income less than $50,000 per annum.

In the USA, marketable credits are created by setting standards and allowing vehicle and/or fuel suppliers to average around the standard: if they do better than the standard, then they are allowed to bank and trade those excess credits, thus creating a market - with marketable credits as the currency - for whatever attribute is being regulated. The trading of greenhouse gases is quite feasible, although not as yet implemented anywhere in the world. Although averaging and banking of attributes are not essential components of marketable credits, they do provide flexibility and lead to much greater efficiency in attaining standards. Averaging gives manufacturers the flexibility to average emissions across their fleet of vehicles; with emissions being lowered the most in those vehicles where the cost of reducing emissions is least and to not reduce emissions as much in other vehicles where the cost is greater, provided the average for all vehicles was below the standard.

Emission banking allows manufacturers to bank emissions from years they outperform the average for use in years when they fall short. Banking is especially critical to trading schemes; since banking rules allow trades to occur when and where they are needed and desired. Emission banking also provides an incentive to introduce new technologies and products sooner in anticipation of continuing tightening of emission standards. McElroy et al. (1984) showed that the cost savings associated with emission averaging and trading but no banking was 25% compared to a regime of uniform emission standards for the equivalent reduction in total emissions. A major study is under way at ITS-Davis to explore this issue more thoroughly. The Director of ITS Davis (Dan Sperling) believes that the cost savings are much greater than 25%.

2.6 A Note on Cold and Hot Starts

The basis of almost all commentary on the effect on greenhouse gas emissions of automobile use defines "use" in terms of total vehicle kilometres. Unlike total trips, vehicle kilometres does not recognise the incidence of cold and hot starts, and hot soaks, which is recognised as a very important influence on emissions (Guensler et al. 1993). In terms of air quality, for example, 64% of the hydrocarbon emissions from an 8 km trip (39% from a 32 km trip) are due to cold starts (CARB 1989). In the current study we will emphasise both trips and kilometres so that a major source of underestimation of emissions is taken into account. It is however argued in the broader literature that the phenomena of cold and hot starts is more important for local air pollution than for greenhouse gas emissions. Johnson (1993) recognised the potential contribution of trip reduction strategies directed towards particular trips (e.g. commuting) provided there was *no* substitution between trip types, but found little comfort in travel behaviour strategies as significant weapons for emission reductions. The importance of careful analysis of automobile technologies and fuels is reinforced by these findings. In our study we will, where appropriate, adjust the emission index per vkm for the profile of trips.

3. THE MAJOR ELEMENTS OF THE STUDY: A SYSTEM WIDE OVERVIEW OF COMPONENTS AND LINKAGES

The major elements of the study are summarised in Figure 2. There is a logical flow to the structure of the study, which is embedded within the ITS-BTCE strategy simulator (see Section 8). Commencing with a set of instruments to be evaluated in the base year (1991) and subsequent census years 1996, 2000, 2005, 2010 and 2015, we translate each instrument in Table 1 into a set of attributes of vehicles, travel and urban form (Figure 3) which, conditional on the socioeconomic and demographic characteristics of individuals and households, enter a set of choice models to explain individual and household-level travel, location and vehicle choices. The set of choice models derive their empirical content on choice responses and attribute levels from revealed preference data and stated choice experiments. A number of market-clearing rules related to the supply of automobiles, the availability of housing types and land, and travel times are introduced to ensure that the system-wide impacts are allowed for.

The primary emphasis is on the first-order effects of alternative strategies, holding the shape and density of the urban area fixed (but allowing households to change residential location and workers to change workplace location). Some elements of a general equilibrium approach such as are presented by Horridge (1991), however, are introduced at a very broad strategic level with respect to urban form to evaluate the impact of exogenous shocks such as a change in planning rules which favours the construction of medium density housing relative to low density housing. A schematic overview of the behavioural models and the way they are linked internally to each other as well as with a set of exogenous spatial accounting identities is presented below. A more detailed exposition is given in the Task 3 report.

With the exception of the attributes of automobiles and descriptors of residential/workplace locations at a zonal level (e.g. statistical local area - SLA), all of the attributes entering the set of choice models are obtained from a survey of a stratified random sample of individuals in households in six capital cities - Sydney, Melbourne, Brisbane, Perth, Adelaide and Canberra. The data will be collected using a computer aided telephone interview (CATI), a one-day trip diary and a follow up face to face interview (see Section 5). The vehicle attributes (including price, scrappage rate, and population of registrations) will be obtained from a number of sources (Figure 7). The primary sources are the ITS vehicle attributes file, updated to 1993, the 1991 ABS Transtats database and enhancements for vehicle registrations by selective attributes necessary to develop vehicle classes, and for scrappage rate modelling, an historical time series of vehicle registration data from the ABS, State-wide transport and planning agencies, and other secondary sources.

A representative sample of respondents for each capital city will be selected and used in the estimation of the choice models. These sampled individuals and households will be the basis for determining model parameters but will not be used as the sampled population for model system application. The parameterised empirical models in the base year and each forecast year are implemented through a set of *synthetic households*. A synthetic household is defined by a combination of levels of socioeconomic variables which describe a type of household in the sampled population. The incidence of each type of household in the population is defined by a population weight to enable expansion up to the total population. The criteria for defining a synthetic unit will be socioeconomic characteristics of the household (e.g. income, household size, and life cycle - see Figure 7). The selected criteria must be explanatory variables in the suite of behavioural choice models and be readily available from the ABS.

Figure 2. Overview of the ITS-BTCE Greenhouse Gas Emissions Study

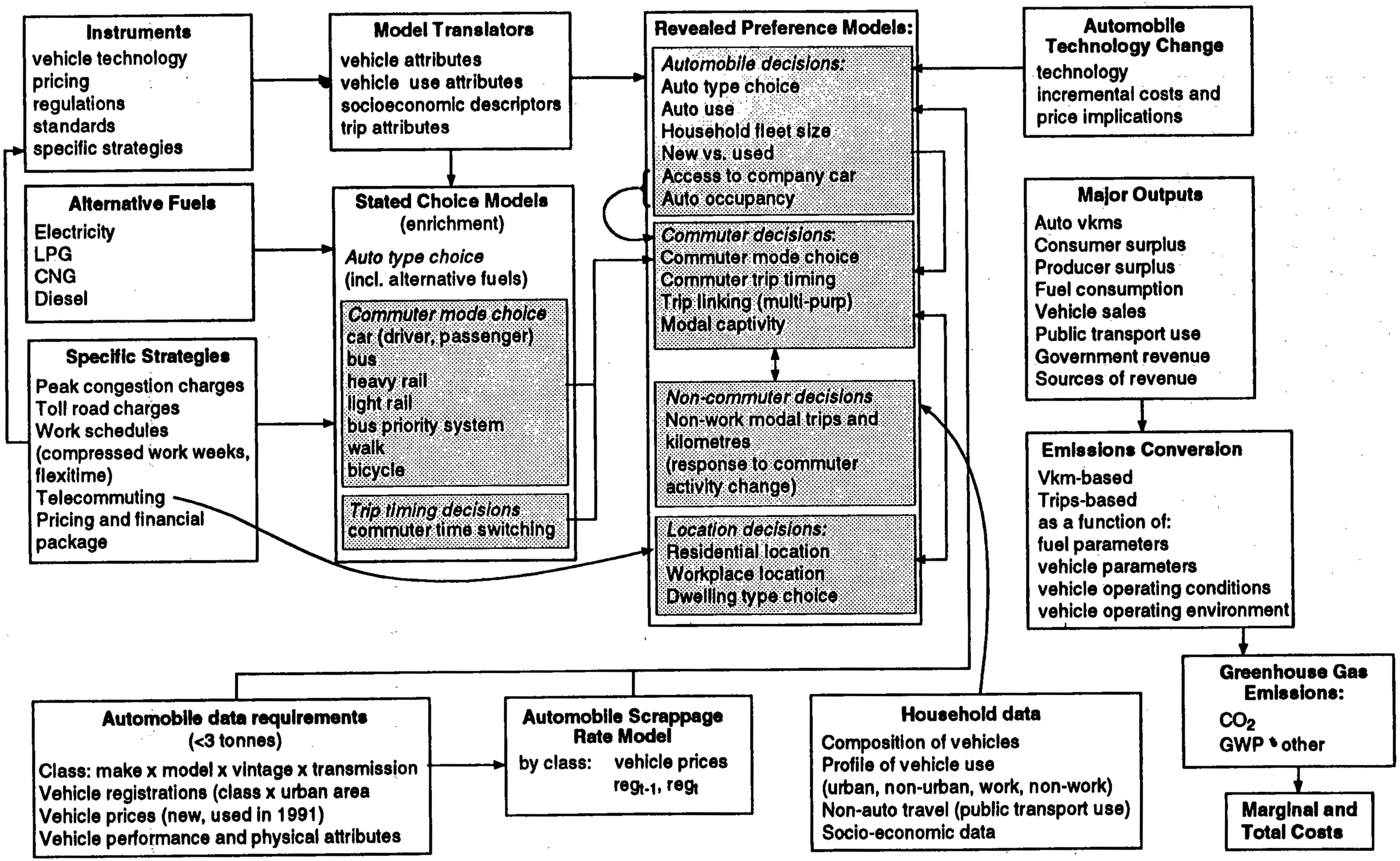


Figure 3. Preliminary Hypotheses on Attributes Influencing Revealed and Stated Choice Travel and Vehicle Choices

Auto Type Choice

body type (sedan, wagon, pvan/ute, lcv)
purchase price
fuel cost
recurrent maintenance cost (c/vkm)
transaction cost (dummy)
gross weight (kg)
vintage*
insurance rating (NRMA scale)
luggage capacity (m^3)
seating capacity*
external dimensions (h*lw*)
number of cylinders
acceleration (0-100kph)
transmission*
no. of models in class
no. of regns in class
household income
refueling/recharging time at home
refueling/recharging time at service station
top speed
tailpipe emissions
air conditioning
fuel consumption (city, highway cycle)*
no. of gear ratios
axle ratio

* reported in Fuel Consumption guide (DPIE)

Fleet Size Choice

vehicle registration
no. of commuters working in/close to CBD
annual household income
no. of workers (full time, part time)
age of household head
lifecycle stage
inclusive value from mode choice and auto type choice

Automobile Use
(annual vkms) (vehicles in household)

unit fuel cost (c/vkm)
age/newness
registration category (3 types)
recurrent maintenance costs
registration and insurance fees
residential location
workplace location of each
no. of workers (city vs other)
household income ($ pa)
age of primary driver (yrs)
occupancy on commute
gross vehicle weight (kg)

% kms: to/from work
as part of work
to/from shops
to/from education
other travel in urban area
non-urban business travel
non-urban non-business

Unit Fuel Cost

fuel consumption
no. of cylinders
registration category
age/vintage

Residential Location Choice

distance from city, regional centre
household income
familiarity with area
accessibility (from commuter mode choice)

Workplace Location Choice

occupation
education
residential location

Auto Occupancy
(commute) (hhld member, other - pool)

workplace location
trip timing
nature of work (flexibility)
no. of workers in household
trip linking (school children)

Access to Company Car
(Other business registered

highest personal income
(or household income)
occupation

Interrelationship Between Commute and Non-Work Travel
(each person in hhld)

On sampled day, identify:

Activity time use:
Commuting time (linked to commute mode and timing choice)
Non-commuting travel time
Working time
Home time
Out-of-home time (non-work plus non-travel)

Kms by activity
Number of trips
Household size (adults/children)
Lifecycle stage
Workplace location (CBD, other)
Modes used
Commute departure time

Commuter Mode Choice

in-vehicle time
walk time
wait time
no. of transfers
in-vehicle cost (fuel, fares)
parking cost
parking availability
access to company car

Modal Captivity
(work trips)

workplace location
personal/hhld income
no. of automobiles available

Commuter AM trip timing
(alternative times of the day)

trip travel times (mean, var)
travel cost (fuel, tolls, charges)
average travel speed
flexible work start indicator
day of week sampled
commuter's age
passenger constraint
(eg kids to school)
delay due to congestion
leave early due to congestion
job type indicator

Dwelling Type Choice

house prices
household income
household size
lifecycle stage

3.1 The Logical Structure of the Overall Base-Year Modelling System: The Revealed Preference Models

The heart of the modelling system is a set of inter-related automobile, travel and location choice models, together with some market clearing rules. We view the household as the 'natural' observation entity; but recognise that some of the choices to be studied are vehicle-specific or person-specific. Figure 4 highlights the natural relationships between the travel activity of individuals, their mapping into the activity of vehicles, and then the summation up to total household travel activity. In broad terms there are three distinct behavioural components of the model system: the set of automobile decisions, the set of trip-based decisions and the set of location decisions. The structural relationships between these decisions are set out in Figure 5a.

Figure 4. Schematic Linkage Between Emissions and Use

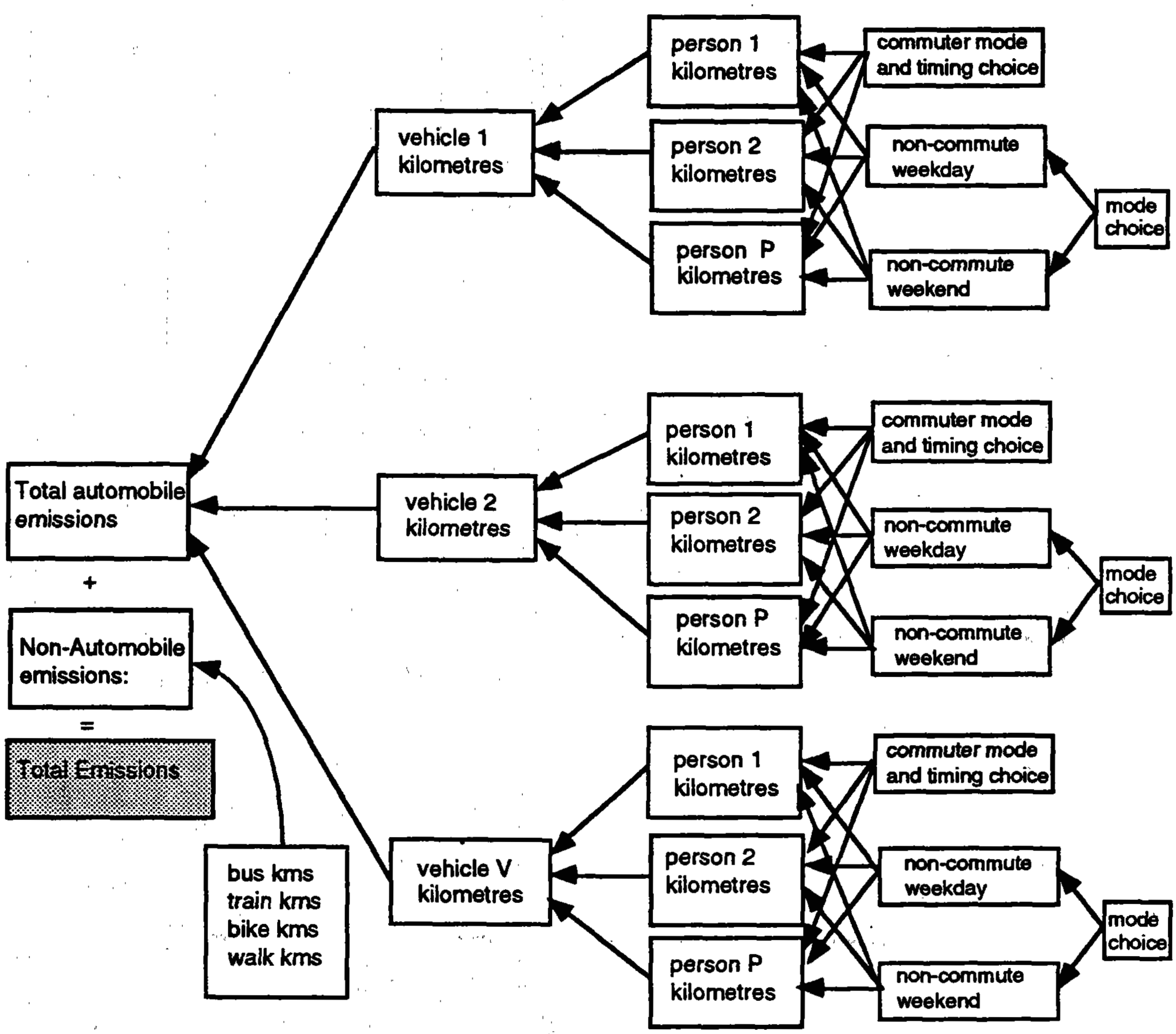
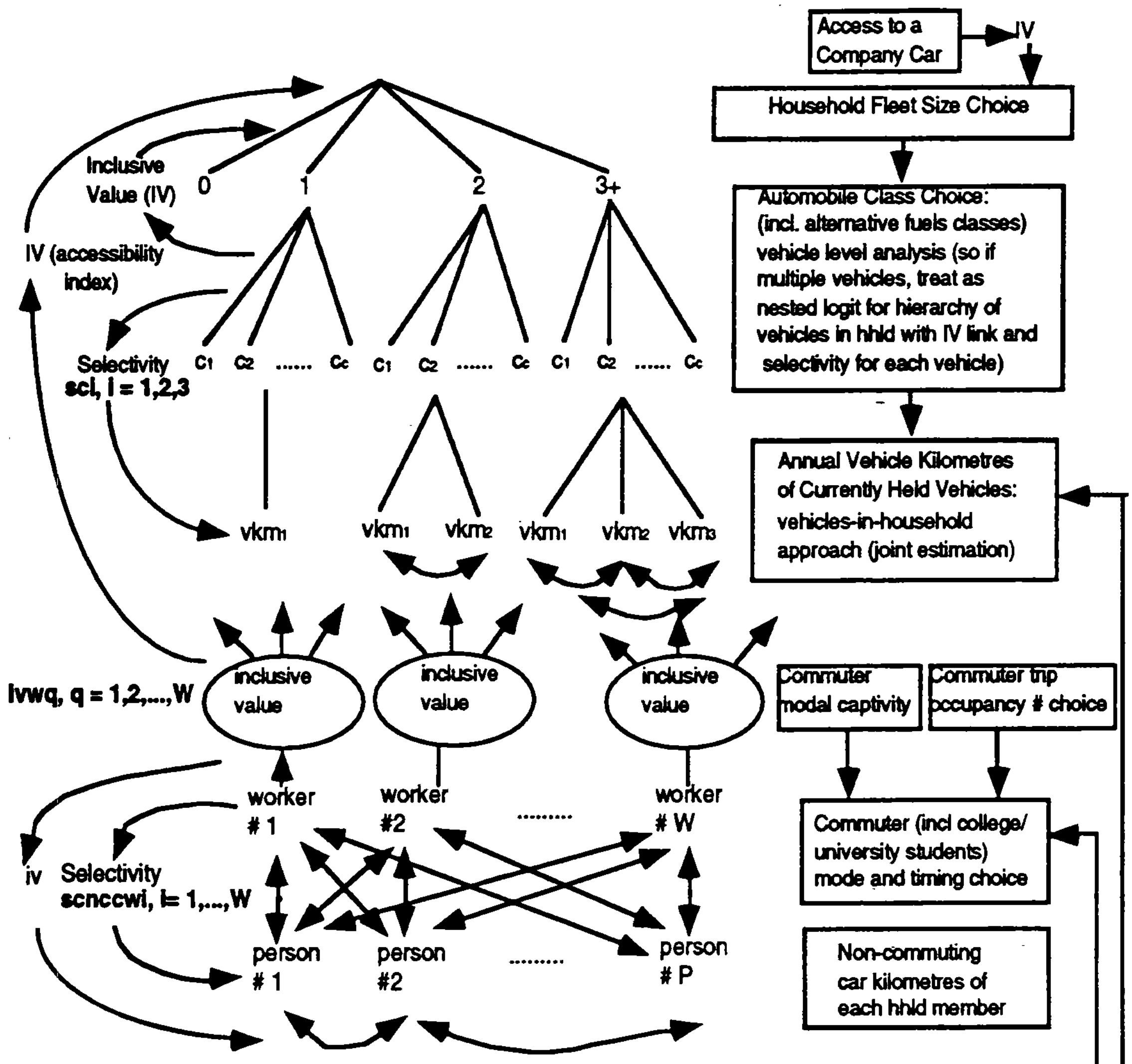


Figure 5a. Structural Relationships Between Vehicle and Travel Choices



Critical Linkage Mechanism: Automobile Use in the Household:

vkm1 = f(**vkm2, vkm3, sc1, Ivw1, Ivw2, ... , IvwW**, household socios)
vkm2 = f(**vkm1, vkm3, sc2, Ivw1, Ivw2, ... , IvwW**, household socios)
vkm3 = f(**vkm1, vkm2, sc3, Ivw1, Ivw2, ... , IvwW**, household socois)

} vehicles-in-household system of equations

Critical Linkage Mechanism: Commuter Mode Choice in the Household:

commuter mode choice for worker 1 = g(modal atts, worker 1 socios, hhld constraints, **nckmw2, nckmwW, nckmothers, scnccw1**)
commuter mode choice for worker 2 = g(modal atts, worker 2 socios, hhld constraints, **nckmw1, nckmwW, nckmothers, scnccw2**)
commuter mode choice for worker W = g(modal atts, worker W socios, hhld constraints,**nckmw1, nckmw2, nckmothers, scnccwW**)

Critical Linkage Mechanism: Non-Commuting Car Kilometres (ncck) in the Household:

ncck for person 1 = h (scnccw1, scnccw2, ..., scnccwW, ncck non-workerW+1,..., ncck non-worker N, socios)
ncck for person 2 = h (scnccw1, scnccw2, ..., scnccwW, ncck non-workerW+1,..., ncck non-worker N, socios)
ncck for person 3 = h (scnccw1, scnccw2, ..., scnccwW, ncck non-workerW+1,..., ncck non-worker N, socios)
ncck for person N = h (scnccw1, scnccw2, ..., scnccwW, ncck non-workerW+1,..., ncck non-worker N, socios)

3.1.1 Automobile-Related Decisions

The set of automobile decisions made by the household or a subset of individuals in the household are dominated by three choices: how many vehicles to 'own' (fleet size choice), the types of vehicles to own (vehicle type choice), and the rate of use of each vehicle in the fleet (annual vehicle utilisation). Previous studies (summarised in Hensher et al. 1992) have modelled these three choices at various levels of disaggregation.

Fleet Size Choice

Fleet size choice is defined to include all vehicles which are permanently available to a household (ie. normally garaged at the household). This includes company cars in the categories of household-business registered and other-business registered. These represent 60% of all new passenger vehicles and approximately 20% of all used vehicles (Hensher et al. 1992). This excludes fleet vehicles owned by an employer which are not regularly parked at a residence even though they may be used in work activities by a household member. We propose to model the choice between 0, 1, 2, and 3-plus vehicles. Socioeconomic characteristics of the household, access to business-registered vehicles, the location of workplaces in the context of suitable public transport, and an inclusive value index defining the expected maximum utility associated with a mix of vehicle types in each fleet size are the primary influences on each household's fleet size choice. The model will be parameterised by either a multinomial logit or an ordered logit or probit model (see appendix E for explanation) (see below for details).

Automobile Type Choice

This is the most complicated vehicle-related choice model, involving potentially thousands of alternative vehicles, defined in terms of make, model, vintage, body type and transmission. Previous studies have adopted one of two main approaches.

Train (1986) studied the household's choice of vehicle class, where the chosen vehicle belonged to one of the classes. The 120 classes were defined by 10 vintages and 12 categories of vehicles in terms of weight, body type and price. Train modelled the choice between the chosen vehicle and a random sample of 15 alternative classes from the 119 classes not containing the chosen vehicle. Hensher and Milthorpe (1987) experimented extensively with alternative choice set sizes for randomisation of the non-chosen alternatives, and concluded that 15-20 alternatives secured consistent parameter estimates. This finding is only supported empirically where the independence of irrelevant alternatives (IIA) property holds (see below). It is not known what the implications for choice set size are for non-IIA models. For multi-vehicle households, Train defined all pairs or triples of vehicles. The attribute levels of each non-chosen vehicle were defined as the average and the standard deviation for the class. For multi-vehicle situations, Train used the average or total for the mix, depending on which was behaviourally more meaningful.

Allowance for possible bias due to partial allowance for within-class variance was made by the inclusion in the model of variables representing the number of makes and models in a class. These additional variables reflect the average utility that the household obtains in its choice of make and model of vehicle given that it chooses a vehicle from the class. Through these variables the model incorporates the fact that a household chooses a make and model of vehicle within a class and chooses the class with a knowledge of the makes and models within it. Although the exact function for the average utility associated with the make and model choice cannot be calculated without estimating a sub model of make/model choice within class, McFadden (1978) has shown that when the number of vehicle types in a class is large, the exact function can be approximated by the natural log of the number of models within the class and the inclusion of the variances of a number of vehicle attributes. Train's approach is appealing because it estimates the model at a level of aggregation corresponding to the level at which model application typically occurs.

Hensher et al. (1992) used a more disaggregate method, treating each vehicle as a unique alternative, and modelling auto type choice at the vehicle level. With over 4000 vehicle types (based on make by model by vintage by transmission by body type), they sampled randomly 19 vehicles (or vehicle type mixes for multi-vehicle situations) as alternatives to the chosen vehicle (or type mix), and used the attribute levels applicable to each of the vehicles or vehicle mixes. While aggregation prior to estimation was avoided, it was necessary to classify vehicles at the application's stage. Hensher et al. (1992) calibrated a base model by randomisation of vehicles to each class (in contrast to applying class-specific average attribute levels). In projecting to the future however, class average levels of each attribute were used.

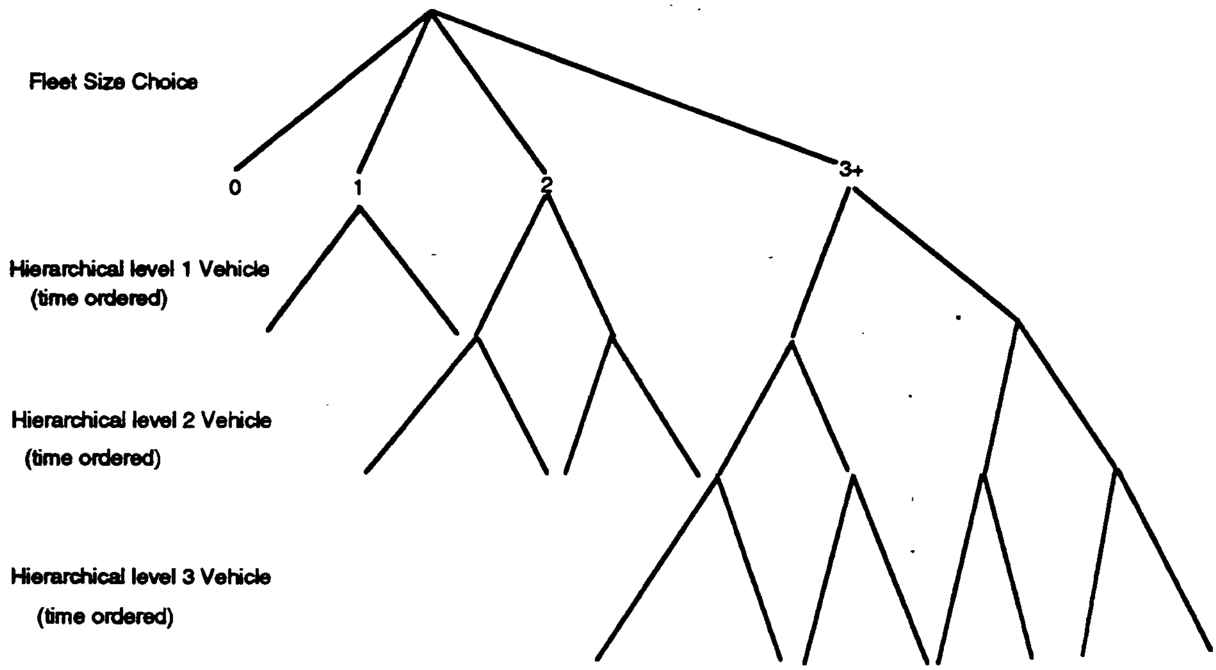
Both Train and Hensher et al. estimated a series of multinomial logit models, treating each alternative as unranked. An unranked model differs from a ranked model in that each alternative vehicle is randomly assigned to one of 16 (for Train) and 20 (for Hensher et al.) 'alternatives' in the choice set. When the number of alternatives in a choice set is large, then an unranked specification is required to enable a sufficient number of observations choosing each alternative. There is no ranked correspondence between a model alternative and a specific vehicle as there is in a ranked model. A ranked model can have 'alternative specific constants' in a multinomial logit model to account for the mean influence of the unobserved influences on choice; in contrast alternative-specific constants are behaviourally meaningless for unranked alternatives.

In the current study we propose to adopt a vehicle-class level analysis, similar to Train (1986), using the class-specific average for each attribute and standard deviation levels for a selective set of attributes. As detailed in Figure 7 (A), we will classify all passenger vehicles (under 3.5 tonnes) by 10 'Paxus' categories, defined in terms of body type, engine capacity, number of cylinders and purchase price, 6 vintage ranges (ensuring that the 1986-87 period in which unleaded petrol was introduced is a vintage grouping), and 2 transmission categories (as a major attribute distinguishing fuel efficiency for the same make, model and vintage). The Paxus categories are the industry accepted classes for new vehicles. Added to these 120 current classes (coincidentally the same number as used by Train 1986), will be a number of alternative-fuelled vehicle classes.

The combining of vehicles within multi-vehicle households is not a satisfactory procedure in the context of studying vehicle emissions. For example, representing the attributes of multi-vehicle households as totals, averages or variances (e.g. average age, total price) fails to preserve the unique attribute levels of each class of vehicle. To enable each vehicle to be treated singularly, we propose to develop a time-ordered hierarchy of vehicles in the household (Figure 5b). The approach defines each vehicle in a household in terms of when a household acquired the vehicle. Starting with the vehicles currently in the household, the date of acquisition is identified. Regardless of whether each vehicle was acquired as a replacement (ie. disposal plus acquisition) or an acquisition only, we will model the choice of the first chronological vehicle in the current household fleet, the choice of the second chronological vehicle in the current fleet conditional on the presence of the first chronological vehicle etc. We are not concerned with the reasons why a household replaced a particular vehicle in the past in the presence of another vehicle. Our interest is on the influence of the chronologically first vehicle in the *current* household fleet on choosing the chronologically second vehicle in the current set for a two or more vehicle household, and the chronologically third vehicle in the current set for the three-vehicle household etc.

Where a household has multiple decision units associated with exclusivity of use of a particular vehicle on most occasions, we will investigate the possibility of redefining a household as a number of decision units (on this exclusivity criterion only) and reduce the fleet size per observation. Household-level characteristics can still be included in the model for each decision unit. Thus, unlike the previous studies, we will estimate the auto-type choice model as a nested logit model in order to preserve the unique attribute levels of each vehicle in a multi-vehicle household. Inclusive value indices will be carried through the auto type choice hierarchy. For each sampled household at each level in the hierarchy, we will identify their chosen vehicle and randomly assign 19 alternative vehicles to be the set of class-specific alternatives. An unranked multinomial logit model is proposed at each level. The inclusive value derived from the 'top' level of the auto type choice hierarchy will become an exogenous variable in the fleet size choice model. A statistically non-significant inclusive value implies that the choice of a vehicle type is independent of the presence of the chronologically older vehicles in the household.

Figure 5b. Automobile Type Choice: Nested Structure



Notes:

1. To establish the household hierarchy of vehicles for multi-vehicle households:
we identify the date at which each vehicle was acquired by the household, and this defines the hierarchy. Level 1 relates to the vehicle acquired first in the set of vehicles currently in the household. Discussions with Fred Mannering were useful in the formulation of the time ordered hierarchy.
2. In recognising the possibility of multiple decision units in a household, we need to ask an additional question: 'is there a vehicle(s) which is available exclusively for the use of a particular household member such that no one else has access to in for the majority of the time. We can treat this as independent of other vehicles in the household and hence redefine the fleet size for the 'household'.
3. The appeal of the nested structure is that it enables us to preserve the identification of each vehicle, which is essential in a study of vehicle emissions.

Annual Automobile Utilisation

An understanding of the influences on automobile use is a kernel of the study, since GGEs are predicted from a knowledge of emission rates per vehicle kilometre. Figures 4 and 5 recognise the importance of identifying the annual kilometres of use of *each* vehicle in the household's fleet. They also highlight the potential interdependence between the use of vehicles in multi-vehicle households. Given that most multi-vehicle households tend to choose vehicles in a way that gives the household the flexibility in transport required for all activities, the degree of substitution between the use of different types of vehicles available to a household can have a significant influence on greenhouse gas emissions. Hensher (1985) found very strong evidence in multi vehicle households that the *use* of each vehicle is not independent of the *use* of other vehicles. Long-run elasticities of vehicle use substitution varied from -0.469 for 2-vehicle households to -0.314 for 3 vehicle households. It becomes important to identify the utilisation profile of each vehicle, to relate this to the use profile of other vehicles in a household, and to relate this profile of use to non-use consequent on choosing a non-automobile mode for some transportation mobility needs. As detailed below, we single out the commuter mode choice activity for particular consideration, given its importance in the fleet size choice, and by implication, the vehicle type choice decision.

For each member of the household we will identify in particular the annual kilometres undertaken in each vehicle, the extent to which the kilometres are shared with other household members, any constraints which act to limit access to particular vehicles (especially as a driver), the composition of annual kilometres in respect of urban/non-urban travel, and trip purpose (journey to and from fixed workplace, journey to and from education, travel as part of work, journey to and from shops, other travel within the defined urban area, and travel outside the urban area). A fuller set of potential influences on vehicle use are given in Figure 3. One of the explanatory variables is a linkage variable between vehicle choice and vehicle use, called a selectivity index. It is included for one very important reason: we only observe the use of the chosen vehicle(s), not of any of the vehicles randomly selected in the estimation of the vehicle type choice models. Consequently, for applications where we are projecting into a future space where vehicle choice might change, we must have a capability of adjusting vehicle use where it is correlated to any degree with the type of vehicle used. The selectivity index provides the mechanism for adjusting vehicle use by the probability of choosing a particular vehicle type (see Hensher et al. 1992 for more details, especially pages 21-23, 30-32).

A separate set of equations for vehicle use will be estimated for each fleet size. For multi-vehicle households, 3 stage least squares (3SLS) regression will be used to allow for the endogeneity between each vehicle's annual kilometres. 3SLS recognises, and allows for, the non-independence of the error structures of each of the equations. The left-hand side (lhs) variable in a single equation is a function of a set of exogenous variables and a set of unobserved effects, the latter generically represented by the error or disturbance term. When the endogenous variable is introduced into a second equation as a right-hand side (rhs) variable, it is likely that the error term of the first equation will be correlated with the error term of the second equation since they potentially measure a number of common influences on both endogenous variables. Failure to recognise this possibility and to allow for it can result in biased parameter estimates of the rhs variables. This becomes a source of misleading inference as to the role of rhs variables in explaining variations in the magnitude of the lhs variable.

Other Automobile-Related Choices

There are three ancillary choices faced by households and individuals which provide useful enhancements to the central vehicle decisions. These are access to an other-business registered vehicle (ie. the company car), choice of auto occupancy for commuter trips, and the choice between acquiring new or used vehicles. The last choice is not strictly consistent with the history-based approach we are using to model vehicle type choice, since we are taking a 'snapshot' at one point in time (i.e. 1993) and seeking details of each vehicle currently in the household's fleet. Although we will identify the date of purchase and whether a vehicle was purchased as new or used, the current choice of new vs used acquisition (in a replacement or addition context) is more in line with a transactions specification of vehicle type choice. The new vs used vehicle question will not be modelled as a choice; rather the opportunity to acquire a new vehicle will be provided in the specification of vintage-specific vehicle classes both up to 1993 (the period of observation) and for each of the forecast periods (see Figure 6).

The auto occupancy choice will be handled through an alternative mode in a commuter mode choice model (see below), and is thus deferred to a later section of the paper. In the current study we will investigate the gain in treating access to a company car endogenously to identify the probability of a household having access to an other-business registered vehicle.

3.1.2 Trip-Related Decisions

Trip-based decisions are broadly divided into commuter and non-commuter activity, but with a recognition that they are not necessarily independent, both for each person and between household members. The presence of multi-purpose trips through trip linking (e.g. a commuter taking a student to school en route to work, with or without a detour) is a direct source of interdependence; but the possibility of adjustments in non-commuting travel behaviour of one person consequent on a change in commuter travel behaviour of the same or other person in the household needs to be accommodated in the overall modelling strategy. The essential linkages are shown in Figure 5a.

The critical trip choices are commuter mode choice, the timing of commuting travel, and non-commuter *automobile* kilometres. We are interested in non-commuting activity because of its importance in the calculation of emissions, and because of the increased opportunities for non-commuting activities by car under many of the strategies to be evaluated. An ancillary modelling consideration is the conditioning of commuter mode choice by a *modal choice of choice sets* model (i.e. modal captivity) to explicitly allow for the 'availability' or 'non-availability' of subsets of modes. Captivity can arise for many reasons, but include the physical non-availability due to the location of residence and workplace, and socio-demographic considerations such as the provision of a company car, lack of a license, the nature of work activity (e.g. travelling salesperson, highly variable late hours), and wealth. Our preference in this study is to begin with the assumption that all modes are available in the choice set, the exception being where captivity is completely unambiguous (e.g. the selfemployed plumber), but to incorporate a sufficiently rich set of exogenous descriptors capable of attaching very low probabilities to modal alternatives that are unlikely to ever get chosen. This has a distinct advantage in application because of the uncertainty about changed circumstance in the future which can bring a currently rejected alternative into greater consideration.

There are a complex set of inter-relationships between household members and their travel activities, as shown in Figure 5a by a large number of arrows. The diagram shows the interdependencies between commuting and non-commuting behaviour within the household. The travel activity of non-commuters is measured in the automobile kilometre models where private transport is used. While in the one-day diary we will identify non-automobile travel for non-commuting activities for each household member, we will not include this in the formal modelling system. Estimates of its incidence in the household's total travel activities will be made and used externally in the calculation of total household contribution to GGEs.

Commuter Mode Choice

An important distinction must be made between a worker and a commuter for the purpose of mode choice modelling. Many workers do travel on a regular basis from a fixed residential location to a fixed workplace location for part or all of a five-day week. Alternative scenarios include travel to fixed but different workplace locations (e.g. the plumber, electrician, builder etc.). Whereas all workers accumulate travel kilometres by various modes, some occupations make a mode choice decision impossible - they are captive to the automobile. Thus we need to limit the application of the mode choice model to that subset of travel kilometres where a choice is feasible. Feasibility could reasonably be defined in terms of the nature of work. We will have to establish some rules for this. We could for example identify work kilometres and assign a mode choice probability of 1.0 to workers whose job requires the use of the automobile either to transport materials and equipment or to undertake the job task at all. This should be imposed prior to model estimation, to avoid any bias in parameter estimates due to forcing a choice.

The commuter mode choice model is defined in terms of six modes: drive alone, driver accompanied by a passenger(s), bus as main mode, train as main mode, walk as main mode, and bicycle as main mode. The main mode is the form of transport used for the greater part of the trip. The last two alternatives will be limited to short commutes and locations where the terrain/weather and safety of the environment is conducive to bicycle use. Automobile occupancy is handled through the separation of single occupant and multi-occupant vehicle use. Where an automobile is involved in a commute, we will have to identify which vehicle it is in multi-vehicle households. This will apply where the car is either the chosen or the non-chosen commuter mode. It is also important for another reason - it will enable us to identify the mapping between each vehicle and each commuter and identify any important constraints on vehicle allocation within the household. For example, one vehicle might be a company car made available to a household head which will never be available for a child or spouse to use except as a passenger. Such constraints must be included in the model, possibly as a dummy variable indicating whether a vehicle is available for another household member to drive for the commute trip. The explanatory variables in the commuter mode choice model would include levels of service (in and out-of-vehicle travel times, in-vehicle cost, parking cost, access to a company car, person specific socioeconomics, the presence of trip linking, and location of workplace). The inclusive value index derived from the mode choice model for each commuter can enter the automobile use equation system. There will be one inclusive value index for each worker. This will condition the use of the automobile by the probability weighted utility associated with each alternative mode available for commuting. This linkage is very important, it being the main way in which public transport strategies can influence automobile kilometres.

The non-commuting automobile kilometres undertaken by each worker and non-worker can be modelled as a system of equations similar in structure to the automobile kilometres model system described above. It differs in that each equation represents a worker or non-worker (not a vehicle). The explanatory variables might include a commuter mode indicator, the travel time on the commute, person-specific socioeconomics, cross-over access to each vehicle for the commute by each household member, household constraints, non-commuting kilometres for each worker and non-worker in the household, and a selectivity index from the commuter mode choice model (set to zero where captivity is applied). 3SLS is the appropriate estimation procedure.

Departure Time Choice for Commuter Trip

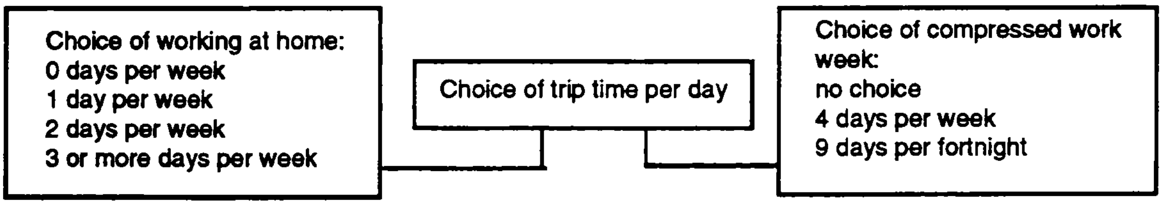
Thus far we have concentrated on the relationship between commuter mode choice and kilometres of non-commuting travel by members of a household, implicitly holding the timing of travel fixed. It is highly likely that a number of the strategies to be evaluated (e.g. congestion charges, parking restrictions, and compressed work weeks) will result in changes in the departure and/or arrival times of trips rather a modal switch. To allow for the observed phenomenon of peak spreading, and to avoid 'artificially' forcing modal switching because of the absence of more realistic options, we will develop a departure time choice model (Figure 6). It will be linked to the commuter mode choice model through the automobile alternatives. Polak et al. (1993) have recently reviewed the literature on choice of time of travel, especially in the context of road pricing, and have developed an empirical timing choice model for four main trip purposes.

In broad terms the timing of travel can be defined in terms of the travel experience, schedule penalties, and participation time penalties associated with the destination activity. Travellers trade off schedule delay against participation time penalty when adjusting changes in travel times or costs. The extant literature suggests that the influences on the timing of travel choice for commuting by car are total cost, total travel time, early and late schedule penalties, increases and decreases in participation penalty, minimum participation time, availability of public transport, the option to not travel (mainly non-commuter activity), the inclusive value from a mode choice model, and a number of socio-economic effects such as ownership status of the automobile (private, company), who incurs the cost of commuter travel, vehicle occupancy, and personal income.

Trip timing for the commuter trip will be modelled using data obtained from a stated choice experiment (see Section 6). In order to accommodate the interdependence between trip timing and the timing obligations of participation at work, we need to design a choice experiment in which the attributes include: (i) the timing of the trip (e.g. earlier or later relative to an appropriate reference point), (ii) duration at the destination (e.g. existing, longer, and shorter periods), (iii) the total travel time (e.g. current, longer and shorter), (iv) and the congestion pricing charge (e.g. no charge plus a number of charge levels calculated on the basis of current trip length in cents/km). Data will be obtained on the current commuting trip's time of day, total travel time, duration time at the workplace, and displacement relative to the preferred departure time from home, and degree of flexibility in timing and duration of the components of the overall activity.

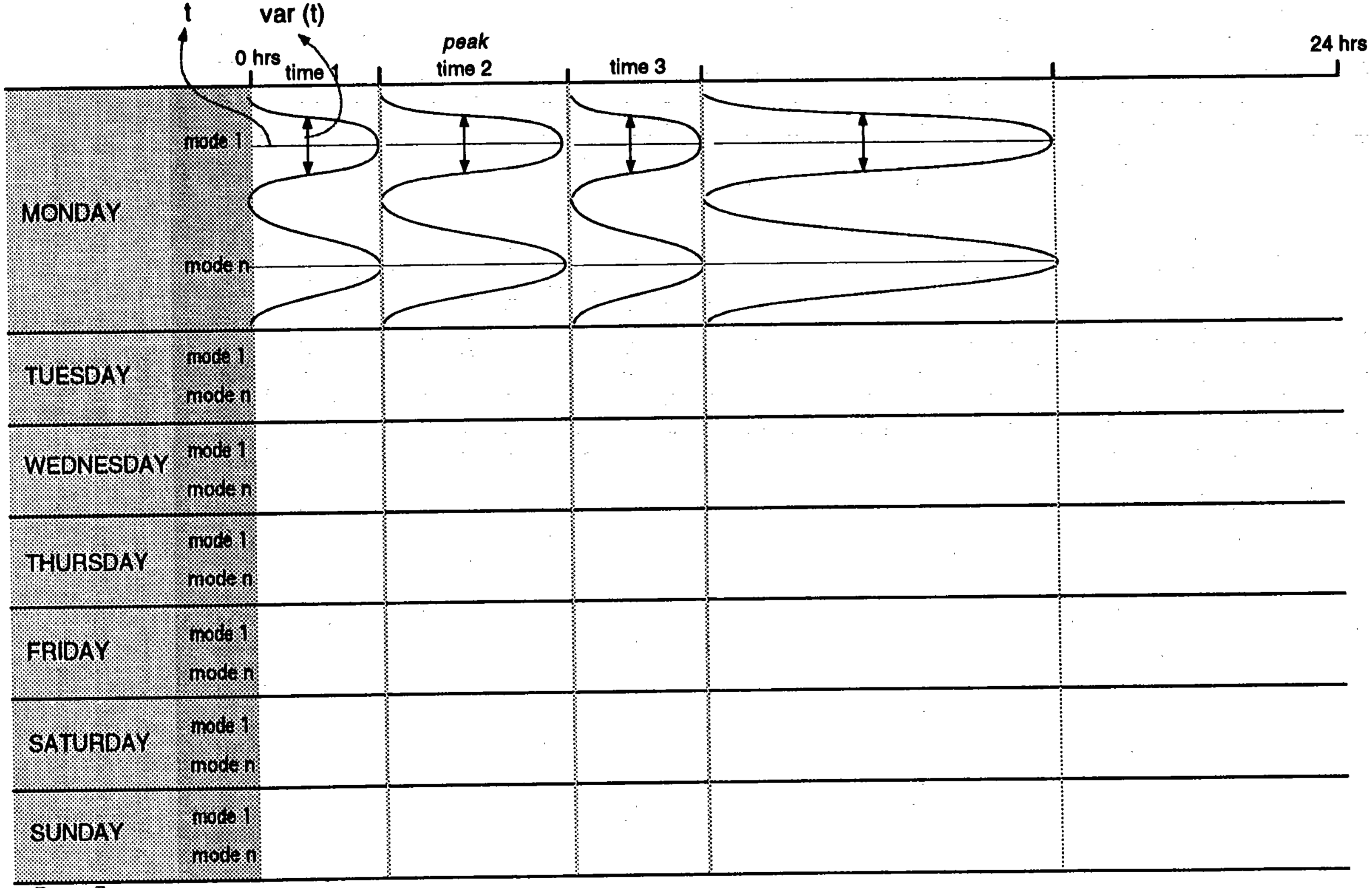
To appreciate the importance of the proposed travel choice structure, assume that we introduce congestion pricing, which is measured through an explanatory variable in the commuter mode choice and trip timing models. This strategy is likely to increase the probability of switching to public transport; it is also likely to lead to some departure time switching for the commute. How do we trace the impact of this strategy to automobile use and ownership? A number of linkages and attributes provide the paths through the model system (Figure 5a) which will be embedded within the ITS-BTCE strategy simulator. Via the inclusive value indices associated with the mode choice model for each commuter and which is included in the fleet size choice model as an index of accessibility, there will be a direct impact on the probability of a household having 0, 1, 2 and 3+ vehicles. This same accessibility index will impact on the kilometres of travel by each vehicle. The selectivity index and/or inclusive value index derived from the commuter mode choice model will be modified to produce a change in the non-commuting car kilometres of each worker and non-worker. The resulting change in each vehicles kilometres provides the necessary prediction for converting GGEs per vehicle kilometre to total GGEs.

The discussion on trip timing thus far has concentrated on the rearrangement of travel within a single day. Some strategies under consideration enable a rearrangement of the entire weekly travel activity. The compressed work week and telecommuting are examples of such strategies. We will identify the ability *and* the willingness of a commuter to have a compressed work week and/or to telecommute, and will use this information exogenously (initially at least) to adjust the amount of weekly (and hence annual) commuting activity. Whereas telecommuting eliminates some travel if the commuter works at home or reduces travel if the worker 'commutes' to a telework centre, the compressed work week may generate new non-commuting travel activity which has to be accounted for. Within the trip timing choice model we have to allow for changes in the hours worked per day associated with changes in the number of days worked per week, and the split of days worked at home and at the official workplace. Schematically the timing of travel can be summarised as follows:



The choices identified above are those of the trip maker. The exogenous influences on the trip makers ability to choose the timing of daily travel, where to work and how many days per week to work will include the employers *current policy*/attitude towards telecommuting, compressed work weeks and different work start and finish times. We have highlighted the phrase 'current policy' to recognise that attitudes towards more flexible work arrangements evolve slowly over time and any one organisation's willingness to support more flexibility is influenced in part by its overall acceptance within society at large (i.e. the bandwagon effect). Consequently in this study we will evaluate scenarios in which differing degrees of acceptability towards increased flexibility are assumed to exist. We will however be dependent on the current preferences of commuters in defining their choice of trip timing, the willingness to telecommute and to adopt compressed work weeks, but with a set of exogenous variables in each choice model to reflect the current policy on the organisation's willingness to let a commuter adopt a particular mode of flexibility in work arrangements. The perceived policy of a commuters employer will be obtained from the sampled commuter. It is assumed that the responses obtained are a reliable indicator of the employers current attitude (but not necessarily their future attitude). Sensitivity testing within this set of strategies will enable us to identify the potential reduction in automobile kilometres and hence changes in GGEs. This study will identify potentially attractive working arrangements consistent with reducing GGEs; actually getting organisations to support these alternative working arrangements is beyond the scope of the current study.

Figure 6. Temporal and Mode Specification for a Given O-D



$$\begin{bmatrix} V_{t1r1} \\ V_{t2r1} \\ \vdots \\ V_{t2r2} \end{bmatrix} = [\alpha_0 + \alpha_1 \bar{t} + \alpha_2 \mathrm{var}(t) + \alpha_3 \mathrm{cost} + \alpha_4 \mathrm{Monday} + \alpha_5 \mathrm{Tuesday} + \ldots]$$

3.1.3 Location Decisions

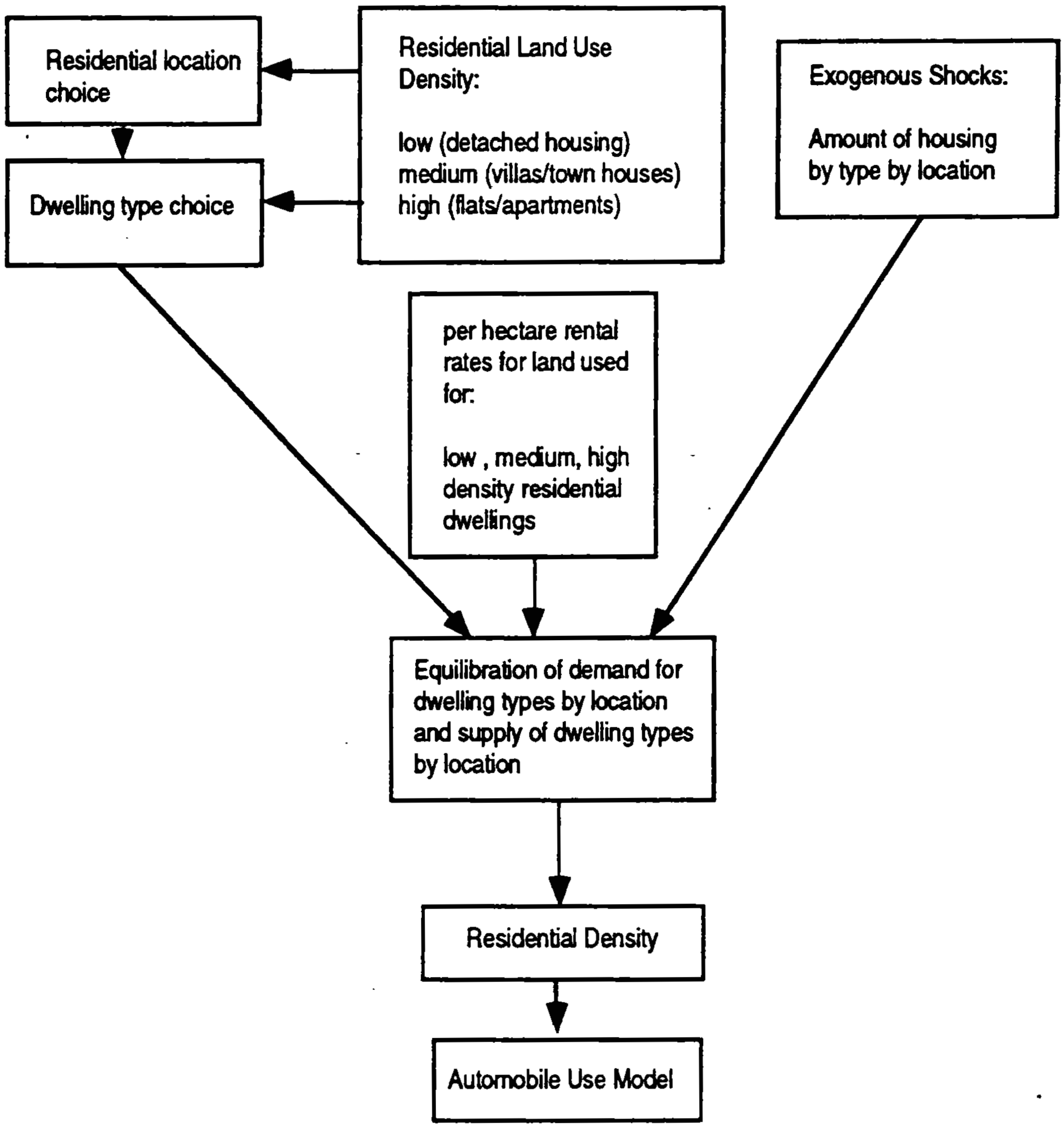
The location of the household's residence and the workplace of each worker have an important influence on travel behaviour (Niemeir and Mannering 1993, Waddell 1993). They are also influenced by the travel requirements of each household member. To recognise the possibility of a change in residential and/or workplace location resulting from one or more instruments listed in Table 1, we will estimate residential location choice and workplace location choice models of the multinomial logit form. We will test for interdependence between residential and workplace location decisions by structuring the choices in a hierarchical (i.e. nested logit) form as suggested by Waddell (1993). We have to recognise that some individuals make workplace decisions based on predetermined residential location, while others make residence decisions on the basis of predetermined workplace locations. The literature suggests that the choice of workplace is dominant, with residential choice usually conditional on this decision. Regardless of the causal structure of location decisions, the impact on travel behaviour of changed residential and/or workplace locations is sufficiently important to warrant an explicit treatment in the current study. In the current study we are interested in the influence of travel-related variables on location choices and not other effects, although additional non-travel variables have to be included to place the travel impacts in context.

An important issue is the relationship between the imposition of sets of instruments (Table 1) and changes in urban form/land use over time, up to the year 2015 in the current study. The interest is duo-directional - the impact of land use strategies on travel behaviour and vice versa. Giulliano and Small (1993) argue that land use strategies are not effective because even very dramatic controls on new development can have only an incremental effect on the overall land-use distribution and consequently on travel flow patterns within a metropolitan area.

In evaluating relationships between transport and land use it is important to distinguish a number of levels at which linkages can be investigated. It is also necessary to explicitly bound the objectives of this study; i.e. what we will investigate and what we will not investigate. The *first level of investigation* assumes a *given urban form* (i.e. shape, density, zoning). Strategies which influence vehicle and travel choices (e.g. a congestion charge) can affect a household's choice of residential location, and even a workers choice of workplace location, but the available residential accommodation and the available jobs in the base and forecast years remain spatially fixed. That is, households and workers relocate within the fixed supply of housing and jobs available within each SLA. If, as a result of household and/or worker location changes there is a shortage of stock of housing and/or jobs in each SLA, clearing procedures for equilibrating the land market are invoked.

The second level of investigation allows for *changes* in the mix of densities of residential living and hence the density profile of the urban area. The spatial profile of jobs, however, is fixed exogenously. Residential land use can change by the introduction of exogenous 'shocks' such as a change in planning controls which favour the construction of high to medium density housing (flats, villas, town houses) relative to low density housing, or which facilitates the conversion of land used for houses into that used for villas/town houses and flats. The conversion of detached houses into sets of villas is already taking place. To accommodate changes in the mix of dwelling types we will develop a dwelling type choice model for three alternatives: detached houses (low density), villa/town houses (medium density), and flats (high density). Specific densities will be identified for each location defined at the Statistical Local Area (SLA) level in each urban area.

By defining dwelling types according to the amount of land area required (i.e. plot size) we have a nice way of handling substitution between different intensities of land use and hence a mechanism for quantifying the adjustments in urban population densities under alternative strategies. The set of residential location and dwelling type choice models will enable us to predict the amount of residential land demanded by each synthetic household (and the population they represent). By introducing exogenous shocks which impose supply-side scenarios of available housing by type and location, the matching of the predicted share of dwelling types by location (obtained from the set of parameterised choice models under base and other strategies) with the available supply of housing (by type and location) will enable us to determine the price of dwelling type by location (using hedonically adjusted house prices as the simple market clearing mechanism in an equilibrating framework). Together with the other influences on the choice of residential location and dwelling type, we will obtain a prediction of the demand for residential land use for each SLA. To enable us to translate the effect of land use changes on travel behaviour, in particular the use of the automobile, *we have to include residential density (however measured) as an exogenous linked feedback variable in the vehicle use model.*



The level of detail of model specification will be limited to some broad objective measures representing influences on location choice. There is an extensive literature on residential choice and dwelling type choice and a more limited literature on workplace location (see Raimond, in progress). The set of explanatory variables to be evaluated within the residential location choice model are: travel time from a residence to the central city, selective summary characteristics of the housing stock in the area, the type of dwelling occupied by the sampled household, the size and composition of the household (income, age of head, life cycle stage, children in private schools etc.), house price, and accessibility to the workplace of each worker with a fixed workplace location (measured by the inclusive value from the commuter mode choice model).The dwelling type choice (i.e. plot size choice) will be primarily influenced by socio-economic characteristics of the household. The influences on workplace location include occupation, job opportunities, travel time from workplace to central city, accessibility (derived for each worker from the commuter mode choice model), and residential location. The fuller set of potential influences on residential and workplace location are listed below, extracted from a review of empirical studies.

Determinants of Residential Location Choice

Demand-side determinants

Location characteristics

- house price
- types of employment in area
- tenure
- dwelling type
- dwelling size/age
- access to public transport (distance)
- access to major highway
- access to CBD
- vehicle ownership levels in area
- access to services - schools
  - shopping centres
  - sporting/recreational facilities
- environmental amenity (quality of neighbourhood)
  - proportion of houses vs units/flats
  - age of area

Household characteristics

- general socioeconomics (income, age, gender)
- distance to employment for household members
- lifecycle stage/household structure
- vehicle ownership
- vehicle availability for commute
- familiarity (yrs in district/previous house or job locations)
- taxes (capital gains, negative gearing), interest rates)
- perhaps more details of job situation - years of service, flexibility of hours etc.
- impetus to move (inadequacy of previous location or dwelling)

Supply side determinants (effect amount and spatial location of investment)

- Zoning
- Rates
- Taxes (capital gains, negative gearing)
- Interest rates

Determinants of Employment Location Choice

- housing location choice
- qualifications (educational attainment)
- *industry/sector of employment*
- position at work
- general socioeconomics (income, age, gender, workers in household, vehicles)
- commute characteristics (habit formation)
- vehicle availability for commute
- years in current home
- lifecycle stage
- attitudes to public transport, congestion
- *house tenure*

We will estimate the location choice models at the household level, with some explanatory variables being measured at a geographical level. To be able to estimate a choice model, we will divide each urban area into a number of geographical zones. This is required in order to define the choice set of physical locations. We will use the ABS geographic entity called a Statistical Local Area. Each household will reside in one of these zones, and each worker will have their main workplace in one of the zones.

3.1.4 Linking Revealed Preference and Stated Choice Models

The full set of revealed preference models provide a rich set of empirical models designed to explain current behaviour within the confines of available alternatives and existing attribute ranges. A number of instruments require investigation of *new* alternatives and attribute levels outside of the observed range. Some new attributes are also under evaluation (e.g. congestion charges, the kilometre range between recharges of electric vehicles). The stated choice experimental approach, discussed in Section 6, is designed to complement the revealed preference modelling approach through enriching their parameter estimates in the presence of an expanded choice set of alternatives, attributes and attribute levels.

Stated choice experiments will be designed for (i) automobile type choice to incorporate alternative-fuelled vehicles and substantial increases/decreases in various costs of motoring - fuel taxes, sales taxes, registration fees (ii) commuter mode and departure timing choice to incorporate new public transport modes (i.e. light rail, bus priority systems), congestion pricing financial packages, parking restrictions, and alternative work schedules - compressed work weeks, flexitime, and telecommuting. We plan to find a way of seeking additional longer-term propensities to change residential and/or workplace location(s) as a result of some of the strategies evaluated within the choice experiments. One possible way of handling the plurality of possible stated responses to *each* of the stated choice experiments is to allow for responses in terms of commuter mode choice, commuter trip timing, telecommuting and compressed work week (which implies the elimination and possible substitution of trips), and the relocation of work place and/or residence.

4. SOURCES OF DATA TO EMPIRICALLY ESTIMATE AND APPLY THE MODEL SYSTEM

The data requirements for this study comprise a series of new household-based surveys and the compilation of data from secondary sources. The survey data is discussed in the next section. In this section we concentrate on all the required secondary data. A detailed summary of such data is given in Figure 7.

4.1 Identifying Automobile Classes, Registrations and Scrappage Rates

There are currently over 5,000 passenger vehicle types on the road, when defined by make, model, body type and vintage. As discussed in Section 3, this study will classify all passenger vehicles under 3.5 tonnes into a number of classes, and undertake all choice modelling and applications at the vehicle class level. The specification of vehicle classes has to be guided by the primary objective of establishing high levels of homogeneity of vehicles within a class in respect of energy and environmental criteria. The particular interest is in vehicle fuel consumption (litres/100km) and vehicle emission rates (CO_2 equivalents in kgs/vkm). Furthermore, the commonality of interest in vehicle emissions between this study and other Australian research, especially the in-service vehicle emissions study coordinated by the Federal Office of Road Safety, suggests the need to establish classification criteria which are adopted by all studies interested in predicting vehicle class-specific energy and environmental indices.

As a starting position, we classify on vehicle vintage and transmission (manual vs automatic), since there is a known correspondence with fuel consumption and emissions. Vintages will be grouped into a manageable number which reflect the major periods in time where some noticeable change in vehicle technology occurred which was designed to improve the fuel efficiency of vehicles. The introduction of unleaded petrol (1986-87) requires explicit treatment. An additional dimension of class is required to accommodate the variation in fuel efficiency within a vintage and transmission grouping. Historically, the classification has been based on engine capacity, weight, number of cylinders and price, the latter being limited to new vehicles. A vehicle once assigned to a class when new remains in the class over time. In Figure 6 we propose 10 categories of vehicles derived from the original Paxus classification adopted by the automobile manufacturing and retailing sector as modified by Hensher et al. (1992) to provide a richer distinction between the smaller vehicles, and to reflect the increasing popularity of an essentially new class of vehicle which has entered the market since 1988. Examples of vehicles in each Paxus category up to 1990 are given in Table 2, together with 1988 market shares for new and used vehicles.

Table 2. Illustration of the 1990 Vehicle Categories Mix using the Projection Categories for New Vehicles
(parenthesis define new and used vehicle market shares within the new and used categories)

Mini (4.78, -)

Holden Barina
Daihatsu Charade
Hyundai Excel
Mazda 121
Suzuki Swift

Medium (32.25, 32.3)

Holden Apollo
Toyota Camry
Toyota Camry V6
Ford Corsair
Telstar
Mitsubishi Magna
Mitsubishi Nimbus
Mitsubishi Galant
Mazda 626 (incl Turbo)
Nissan Pintara
Honda Accord
Hyundai Sonata 4,6
Suburu Liberty

Upper Luxury (4.04, 2.2)
Mercedes
Porsche
Rolls Royce
Volvo 740/760
Saab 9000
BMW 500 Series
BMW 700 Series
Jaguar/Daimler
Rover
Range Rover
Honda Legend
Ford LTD
Holden Caprice

Small (20.9, 25.0)

Mazda 323
Holden Nova
Daihatsu Applause
Honda Civic
Mitsubishi Lancer
Mitsubishi Colt
Toyota Corolla
Ford Laser
Nissan Pulsar
Subaru Leone

Sport (1.95, -)

Ford Capri
Toyota Celica
Toyota MR-2
Honda Integra
Honda Concerto
Honda Prelude
Mazda MX-5
Nissan EXA

Upper Medium (33.12, 30.2)

Holden Commodore 6
Holden Commodore 8
Ford Falcon
Ford Fairmont
Toyota Lexcen
Nissan Skyline

Luxury (2.84, 10.3)

Holden Statesman
Ford Fairlane
Toyota Cressida
Peugeot
BMW 318
Mazda 929
Nissan Maxima
Volvo 240
Saab 900

Source: Hensher *et al.* (1992)

The 10 Paxus categories, 6 vintage ranges and 2 transmission categories give us 120 vehicle classes up to 1993. Added to these 120 classes will be the new alternative fuel vehicles, evaluated in the stated choice experiments and introduced into the estimation of automobile type choice. Beyond 1993, additional classes are created to represent the introduction of 20 new vehicle classes per new vintage range. As shown in Figure 7, 20 additional classes will be added in the application year 1996, with an additional 20 classes added each application year. By the year 2015 we would have added 100 classes giving a total of 220 plus alternative-fuelled vehicles. It is possible through time that the older vintage classes in the seventies and eighties will be collapsed into broader vintage ranges, to recognise the impact of scrappage on the share of the total car park within the very old vintage categories. By 2015, the early 1980's vehicles will be 30 plus years old. The strategy of aggregating older vintage classes as we add new vintage classes is an appealing strategy. It is a correct strategy, avoiding the temptation to replace vintage classes with age classes. The latter is a very incorrect practice since it fails to allow for period-specific technology enhancement (for example, it assumes a 6 year old vehicle in 1980 has the sample durability properties as a 6 year old vehicle in 1990).

The classification of vehicles requires data on a select number of vehicle attributes. ITS has a data base up to 1988 which includes all the vehicle attributes (including price) required to classify vehicles. The data base represents all passenger vehicles under 3 tonne on the road up to 1988. This data base will be updated to 1993. What is still required however is the total number of vehicle registrations in each class by location (i.e. urban area). The registration data has recently been compiled by the Australian Bureau of Statistics (ABS). Transtats (ABS) provides registrations by our classes (based on the vehicle attributes selected), by location and by vintage for 1991, and possibly 1993 by early 1994. What is missing however is transmission, except for Victoria (i.e. Melbourne) and Western Australia (i.e. Perth). A procedure for predicting the transmission mix for the other urban contexts is proposed in Figure 7.

Except for identification of vehicle class scrappage rates, registration data is only required for 1991 and 1993. The scrappage rate model requires data on loss rates between pairs of years through time, so that we can allow for period effects. This is very important, because of the evidence that loss rates vary significantly over time according to the economic climate and vehicle technology. Since loss rates are explained by vehicle price (which may be correlated sufficiently with GDP to use it as a suitable period effect), physical attributes of vehicles and vintage, it is necessary to obtain data for a number of years. ABS has registration data for the years 1982, 1985, 1988, 1991 and (in progress) 1993. The 1982 and 1983 data are not available on electronic medium (Figure 7), with 1982 being available only as hard copy. We propose to develop a scrappage model based on loss rates for the 120 vehicle classes for the years 1988-85 and 1991-1988, and if available in time for 1993-91. Full details of the econometric form of the vehicle scrappage model is set out in Appendix C. The format of the vehicle data is given in Figure 8.

4.2 Socio-Demographic Data and Synthetic Households

Having established a secondary data base for the entire on-road passenger vehicle fleet, stratified by urban area and vehicle class, which gives class-specific data on vehicle attributes, number of registration and scrappage rates, we have to relate this information to households in the sampled population. Households in the sampled population are treated differently in model estimation and model application. In model estimation, we rely exclusively on the socioeconomic data obtained from the series of new surveys. This data, documented below in Section 5, is obtained for each household member, and is introduced in the set of choice and vehicle use models as important conditioning influences on behaviour. In contrast, once the set of models are estimated, the application phase (i.e. base year and each projection year) will use a set of *synthetic* households as a representation of current and future populations. A synthetic household is a household with particular socioeconomic characteristics and a population weight to indicate the incidence of such a household in the base and future populations. The characteristics of each household will not change over time; the weight will vary over time to represent the changing incidence of each household type.

Synthetic households have to be defined on a number of socioeconomic dimensions. The selection is constrained by the availability of population-wide data and the reliability of these base year dimensions as projection criteria in *carrying* synthetic households through time (i.e. the reliability of the population weights through time). The 1991 census will be the data source for constructing synthetic households in the base year. To manage the design of such households, it is convenient to distinguish a set of core socioeconomic criteria and a set of non-core criteria. The proposed core socio-demographic variables are stage in the life cycle and household gross income. They are used to specify a multi-way contingency table, and in the forecast years when only marginal distributions of each variable is known, used to generate cell numbers using iterative proportional fitting (applied using the ITS-IPF program), given projected marginal distributions. Within each of the core cells, distributions are established for the non-core socio-economic variables which are explanatory variables in the vehicle and travel choice models. It is essential that the core and non-core socioeconomic variables are limited to the set of explanatory variables found to have a significant influence on travel and vehicle choice, because it is through this linkage that the model system can be effectively implemented.

Some proposed core variables and their possible levels are:

A. Stage in the life cycle:

1. young adults: < 35 years, no dependent children
2. young adults: < 35 years, ≥1 dependent child
3. older adults: 35-64 years, no dependent children
4. older adults: 35-64 years, ≥ 1 dependent child
5. over 64 years old

B. Gross household income [constant 1991 $'s per annum]

1. under $20,000
2. $20,000-$35,000
3. $35,001-$50,000
4. $50,001-$70,000
5. over $70,000

The number of cells will be 5*5 = 25. Within each cell, which defines core synthetic households we define distributions for non-core variables such as:

1. Number of driving licences in the household
2. Number of full time workers
3. Number of part time workers
4. Number of persons working in or close to the CBD
5. Whether household rents, is buying or owns the residence.
6. Access to an "other-business registered" vehicle.

The ABS data required to obtain the full base-year cross-tabulation of incidence of households in the population of households in each urban area is not available on the CD-Rom file (CDATA91). The latter provides selective pre-determined cross-tabulations and marginal distributions. It is important that base year contingency tables are accurately developed at the population level; this will require a special request to ABS to provide the multi-way tables for 1991 for each urban area, for core and non-core socioeconomic variables. In preparing the non-core cell values, the following procedure is proposed to ensure that each core cell has sufficient synthetic households representing a distribution of profiles in terms of non-core variables:

1. Assume a total of 20 synthetic households to be generated for a core cell.
2. Cross-tabulate number of children [0,1,2,3+] by no. of adults [1,2,3+], with each of the 12 cells defining the *proportion* of households satisfying the levels of the two variables. Generate 20 synthetic households from this table, by random sampling. This step defines the household size and composition.
3. Cross-tabulate the number of children against the age of household head [≤ 25, 26-35, 36-45, 46-55, 56-65, >65], and for each of the 20 households defined by household composition, randomly select an age of household head from the cells satisfying the number of children selected from step 2.
4. Cross-tabulate the number of adults against the number of workers [0,1,2,3+], and randomly select the number of workers conditional on the number of adults.
5. Cross-tabulate the number of children against age (< 12, ≥ 12) and randomly select ages of the children conditional on number of children.
6. Cross-tabulate the number of workers against the number of full-time workers [0,1,2,3+], and randomly select the number of full-time workers conditional on the total number of workers.
7. Cross-tabulate the number of workers against the number of commuters working adjacent to or in the central city area [0,1,2,3+], and randomly assign workers to the location of employment [1,0] conditional on the number of workers.
8. Cross-tabulate the number of persons in the household over 17 years old [driving licence eligibility age] by the number of drivers licences, and randomly select the number of driving licences conditional on this number of eligible persons.
9. From the marginal distribution of home ownership [own, purchasing, renting], randomly assign a level within the core cell to each synthetic household. The incidence of tenure within a core cell already reflects household income and stage in the life cycle.
10. Finally, cross-tabulate access to *other-business registered* vehicle [1,0] against the number of full-time workers, and randomly generate a dummy variable for access to such vehicles.

4.3 Projecting Automobile Technological Change Affecting Fuel Consumption and Emissions

The final secondary data requirement is the identification of the technological changes which manufacturers have already included in their *product plan* (P), and any additional changes which are technologically feasible but which require additional incentives to encourage manufacturers to adopt a *maximum technology* (M) strategy in the interest of fuel consumption and greenhouse gas emissions. In 1991 ITS in conjunction with Nelson English (NELA 1991, Hensher et al. 1992) employed Environment and Energy Analysts to identify, for vehicles available in Australia, the technological assumptions underlying the product plan and a maximum technology scenario up to the year 2005. For each technology a unit price was also identified. Discussions with the Federal Office of Road Safety (Peter Anyon and John Weatherstone, September 15, 1993) suggest that the scenarios identified in 1991 are still current, and can be taken to represent technology futures up to 2005. Further consideration up to 2015 will have to be undertaken. The technologies of relevance are (P=product plan; M=maximum technology):

Weight reduction:	P = 5% for all automobiles except Holden Commodore. M = 10% for all except 5% for Holden Commodore.
Drag reduction:	P = C_D = 0.30 ~ 0.31 M = C_D = 0.28 ~ 0.29.
2-Stroke engine:	P= 20% of mini and small vehicles M = 80% of mini and small and 40% of medium.
4-valve engine:	P= all other vehicles except V8, some mini vehicles M = all other vehicles.
CVT (replacing automatic transmission):	P = 10% of mini, small and 20% of medium M = all mini, small and 30% of medium vehicles.
5-speed auto transmission:	P = 50% of upper medium and luxury M = all upper medium, luxury and 40% of medium.
Variable valve timing:	P = 50% of 4-valve engines rated over 75 kilowatts M = all 4-valve engines rated over 75 kilowatts.
Advanced engine friction reduction:	P = all engines M = all engines
Electric power steering:	P = replaces 50% of power steering in mini and small vehicles M = replaces all power steering in mini and small cars.
Improved tyres:	P = all vehicles M = all vehicles.

Each of these attribute enhancements will be used to modify the attribute levels within each of the classes of vehicles introduced in each of the project years.

Figure 7. Data Requirements External to CATI and Face to Face Surveys

A. Defining Automobile Classes as a Requirement for establishing Vehicle Class Loss Rates

Class-based Automobile Scrappage Model:
ln (loss rate) =f(price, gdp, other temporal-specific influences, vintage, weight....)
(estimated by generalised least squares regression where the dependent variable is log (loss rate, t vs t-1)).

Years of motor vehicle census (ABS)	Source
85-82	1982: ABS hardcopy
88-85	1985: ABS microfiche
91-88	1988 - 1994: ABS Transtats (diskette)
93-91	
94-93 (not available for current study)	

Note: given that ABS has reasonably accessible data on registrations for the years 88, 91, and 93, we will utilise the three years only in developing loss rate models

Proposed Automobile Classes

10 Paxus categories:		*6 Vintage ranges:*		*2 transmission categories:*	
Mini	by	93-91	by	manual	**= 120 classes (plus alternative fuelled vehicle classes)**
Small		90-88		automatic	
Sports		87-86			
Medium		85-83			
Upper Medium		82-80			
Luxury		79 and older			
Upper Luxury					
4 wheel drive					
Light commercial					
Light trucks					

The forecasting years will become 5 new vintage ranges: 1994-1995, 1996-2000, 2001-2005, 2006-2010, 2011-2015. applications in each forcecast year will use the following new categories [=x]:

	91	96	00	05	10	15
95-94		x	x	x	x	x
96-00			x	x	x	x
01-05				x	x	x
06-10					x	x
11-15						x

Note: resolution of allocation of each vehicle to a class is essential before we can advise ABS as to our class-specific regns.

ABS has to provide registration numbers for each class, together with the number of models in each class (the latter required for vehicle type choice modelling, to represent the inclusive value index for within class expected maximum utility not accounted for by the class attribute levels and choice process).

ABS does not have a Statewide breakdown of registrations by transmission except for Victoria and Western Australia. A number of strategies can be used to estimate the transmission distribution for each urban area:

(i) assume the same bivariate distribution in Sydney as in Melbourne (recognising the importance of provision of company cars as a bias towards automatics, especially in the upper medium class
(ii) assume the same bivariate distribution in other urban areas as is known in Perth.
(iii) given that the ABS knows the vehicle identification number (VIN) for new vehicles, and is able to decode it to identify the transmission type, we can establish the incidence of manuals and automatics sold in each urban area, and use this as an additional source of information to evaluate the suitability of strategies (i) and (ii).

B. Identifying the Popn of Vehicles by Make, Model, Vintage and Transmission and Allocating to Classes

ITS has an extensive data base of all automobile types on the road from the early 1960's up to and including 1988. These need to be updated to mid-1993. The data base will contain the full range of relevant attributes describing each vehicle's physical and performance dimensions, as well as price through time since the first release date.

Each automobile has to be allocated to a class. To do this, we will have to establish some rules. The PAXUS classification was loosely related to a vehicle's engine capacity, number of cylinders and purchase price, allowing for body type. PAXUS did not have a mini-vehicle class to accommodate vehicles introduced in the late 80s such as the Holden Barina, Daihatsu Charade, Mazda 121, Hyundai Excel and Suzuki Swift. We have separated this out from the Small size class. By further disagregating by vintage and transmission we are giving a depth of richness essential for accommodating fuel consumption and hence emission levels within class.

Figure 7 continued

C. Automobile Choice Models (1993 only)

A profile of all on-road passenger vehicles regularly parked at a household address is required. Data to complement the data obtained in the CATI and face-to-face survey are, in addition to registrations by class and # of models by class as defined above:

(i) Automobile performance and physical attributes
(ii) Automobile prices - new and used in 1993
(iii) Automobile annual utilisation in 1993 - Latest Survey of Motor Vehicle Usage (SMVU - ABS)

The Sources for (i) are Federal Government Fuel Consumption Guide, Glasses Dealer's Guides on diskette, Automobile price guides and the Roads and Traffic Authority (NSW) Vehicle Specification Sheets. ITS has all of this data on computer up to 1988. These sources will enable us to obtain mean and variance estimates of vehicle attributes (including price) for each of the 120 classes. This data will be used in the estimation of the automobile type choice models.

We propose to use class-specific average and variance levels of each attribute rather than the vehicle-specific attribute levels. This gives compatibility with model application which will be at the class level.

D. External Socio-Demographic Data Needs

External data is required for two purposes:

(i) Weighting of the base surveys observations to expand up to the sampled population.
(ii) Weighting up over the forecast period of the exogenous variables which will enable forward projection of the base (i.e. 1993) modeling system for applications in 1996, 2001, 2006, 2011 and 2016.
Requirements for:

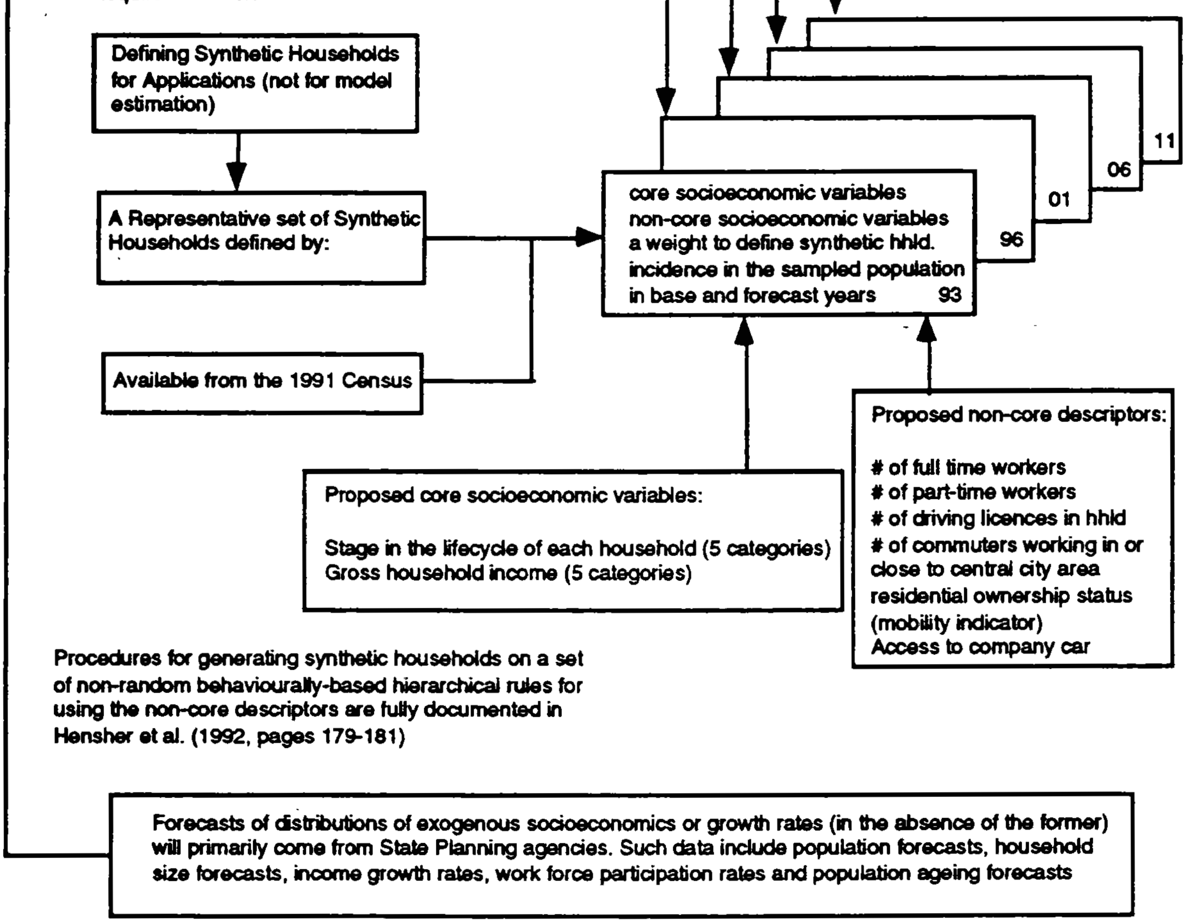
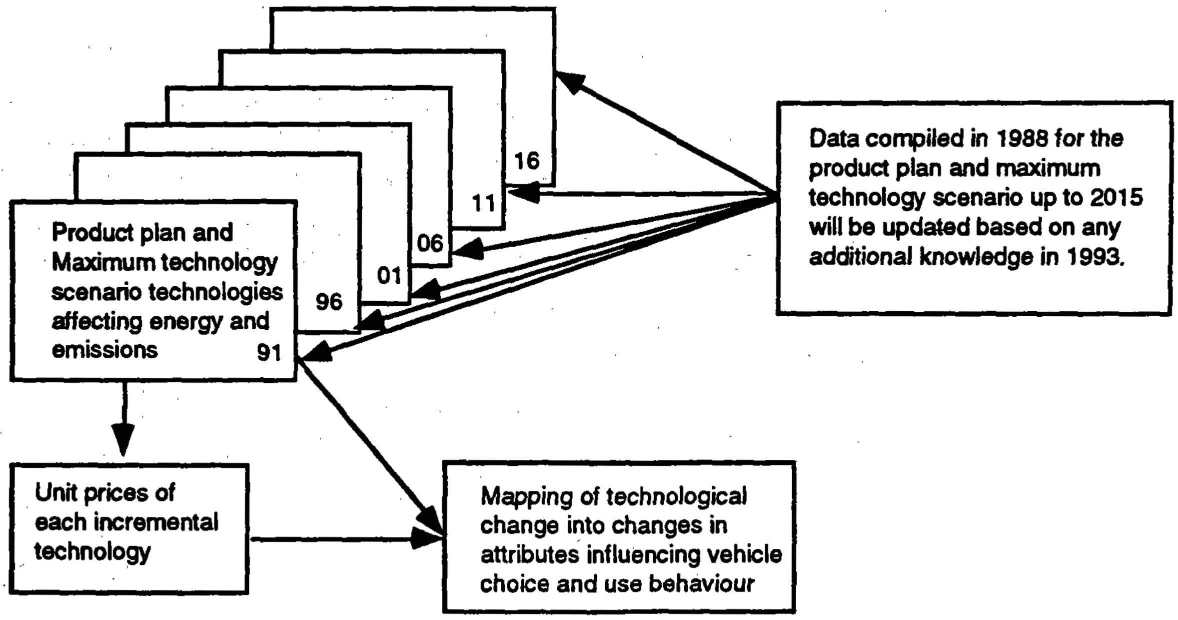


Figure 7 continued

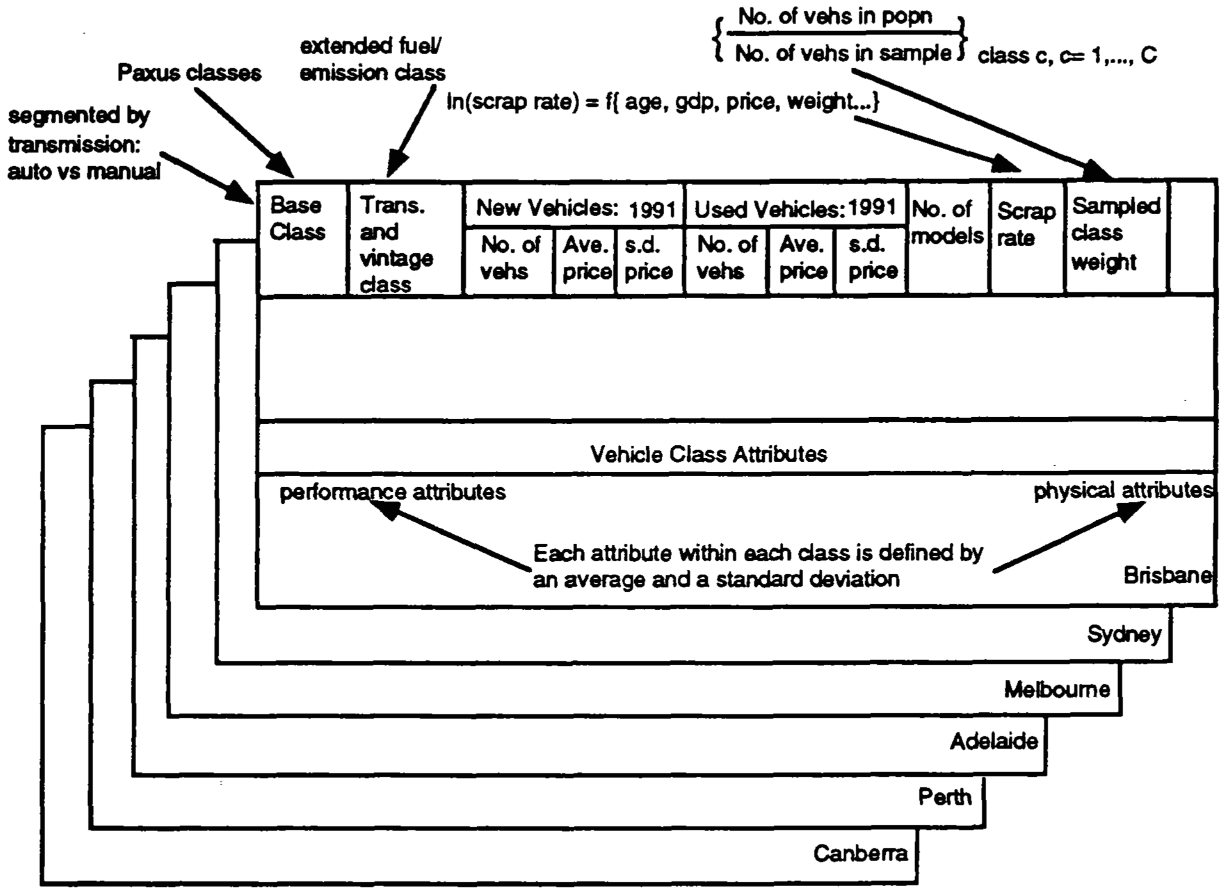
E. Automobile Technological Change, 1993 - 2016

To allow for changes in vehicle technology at the class-specific level which impact on vehicle energy consumption and emission levels, we need to obtain the following information:



Note: the product plan is the known plan of new technology to be introduced in vehicles. The maximum technology scenario represents what is technologically feasible given current research and development and which could be introduced into new vehicles with appropriate incentives to manufacturers.

Figure 8. Specification of Automobile Demand and Supply Data Set Up (Base Year = 1991)



(ave. = average, s.d. = standard deviation)

5. SURVEY STRATEGY AND CONTENTS: THE CATI, MAIL-OUT AND FACE TO FACE SURVEYS

A total of 3500 telephone surveys and 1200 mail-out trip diaries and face to face interviews are proposed. They will be conducted in 6 major urban areas centred on Sydney, Melbourne, Adelaide, Perth, Canberra and Brisbane. These locations account for over 80 percent of Australia's population, and provide sufficient richness in information to enable the set of estimated choice models to be transferred to the remaining urban contexts (principally Darwin and the major urban areas in Tasmania). The population and geographical coverage of each urban area is summarised in Appendix D. The breakdown of the sample by instrument and location is given in Table 3.

Table 3. The Sample Sizes for each Survey by Location

Location	CATI survey	Face to Face Survey
Sydney	1200	300
Melbourne	900	300
Adelaide	350	150
Perth	350	150
Canberra	300	150
Brisbane	400	150
Total	**3500**	**1200**

A pilot survey of 60 CATI and 50 mail-out diaries and face-to-face (FTF) surveys will be conducted to test the contents and logistics of the survey process. As a mechanism for assisting the FTF survey, we propose to mail out a one-day trip diary to each responding household from the CATI survey who is sampled for inclusion in the FTF survey, to be completed prior to the FTF interview. Each household member will be asked to complete a one-day diary for a randomly assigned day of the week, out of the full 7 days. It is essential to capture the trip activities of every household member in order to model the inter-relationships of travel behaviour between household members.

Within each urban area, a multi-stage stratified random sample will be drawn, using three strata criteria: *household size* (or fleet size), *distance from the central area* and *direction away from the central area*. These three criteria will ensure a suitable spatial spread of households as well as accommodating socioeconomic status and complexity of household activity and constraints on travel behaviour. The two locational criteria can be used to select the sample of telephone numbers (based on the first 3 digits of a local telephone number). The household size stratum will be a control question to ensure we meet the locational quota imposed by the known distribution of household sizes within each location strata.

Reark Research will undertake all of the field work, using survey instruments and sampling strategies designed by ITS in close consultation with REARK Research. Extensive piloting of all survey instruments will be conducted by Reark and ITS, with pilot data being available to evaluate the logistics of the data collection approach and the structural content of the survey forms. All interviewers will be jointly trained by Reark and ITS on-site in each urban area. Each component of the fieldwork will be conducted in close succession, a strategy necessary to maximise response rates. The CATI survey will be conducted in early April 1994, to be followed by the mailing of a questionnaire within two days of telephone contact. A face-to-face interview will then be scheduled for later in April on a day soon after the mail out travel diary is to be completed. The sequence of survey tasks is summarised in Figure 9.

The data to be collected by the various surveys will form the major data input into the estimation of all the base year choice models. The main supplementary data relates to the attributes of the non-chosen alternatives for vehicle, travel and location choices. For automobile type choice this includes the relevant set of vehicle attributes and prices. For residential location choice this includes the physical description of each SLA as well as some indicators of amenity, access and price. For the commuter mode choice model the levels of service and costs of alternative modes will be derived in part from asking each sampled commuter to report their perceptions of the levels of travel times and operating costs/fares, as well as distance travelled in each main mode. Careful editing will be required to establish confidence in service levels of non-chosen modes. For departure time choice for the commuter trip, we will seek estimates of travel times at two other times of the day. The definition of a 'time of day' has yet to be finalised, but will be important in the estimation of the departure time choice model.

Figure 9. The Survey Collection Strategy

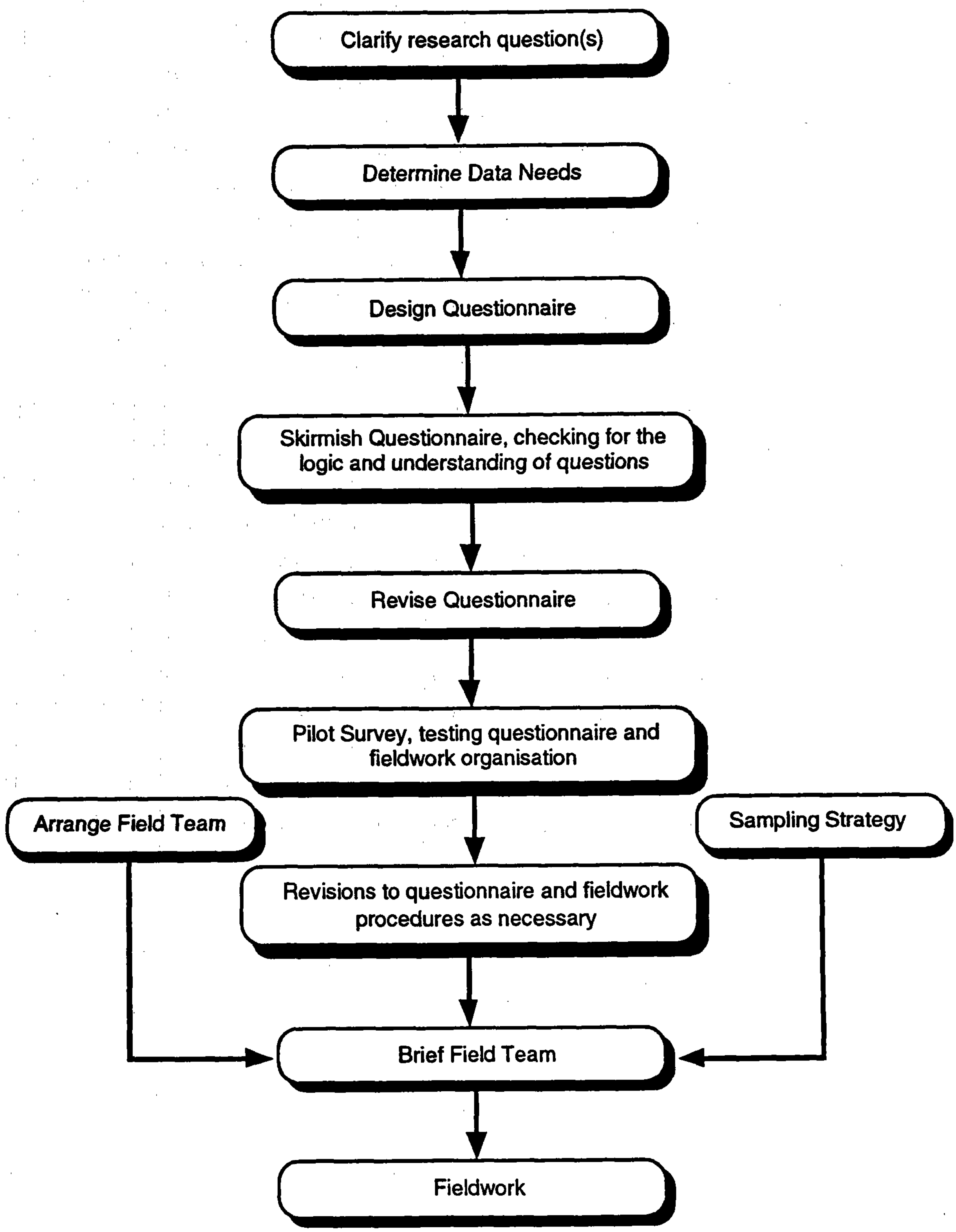
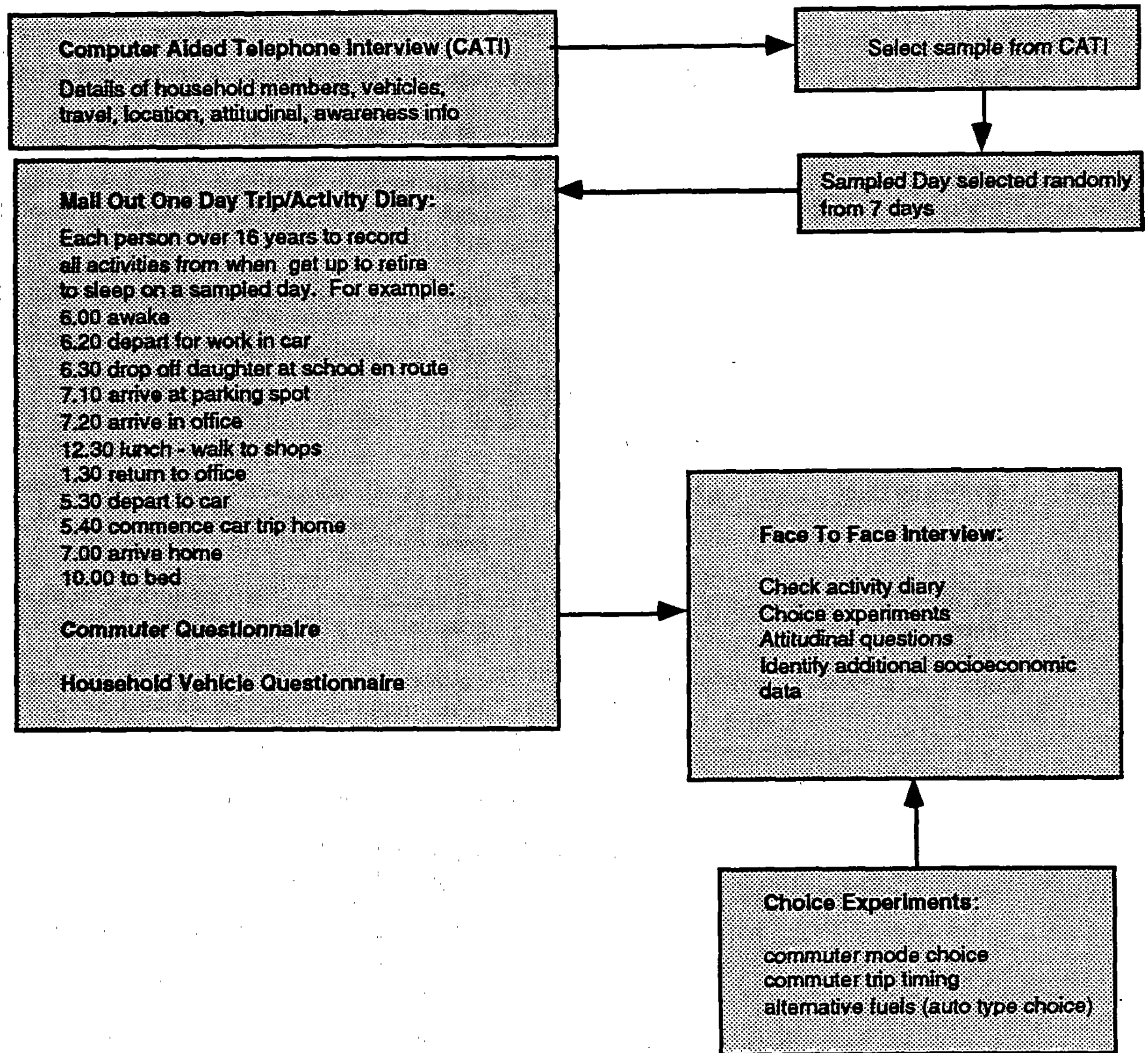


Table 4. An Overview of the Contents of Each Survey Instrument

Survey	Category	Data Item
CATI	Person Socioeconomics	Age, sex, employment, licence, vehicle used
	Hhold Socioeconomics	Size, lifecycle, residential locn
	Vehicle Attributes	Make, model, year, transmission, purchase year, body type, registration, no. of cylinders, other attributes
	Awareness and Attitude	towards energy and environment, alternative fuels
	IFollow-up Surveys	Willingness to participate, address
MAIL OUT		
Trip/Activity Diary	For each trip by hhld	origin, destination, start/finish times, mode(s), cost, (multi) purpose, travelling party - size and composition, constraints, trip linking
Household vehicle survey	Vehicle use	Annual use by trip purpose (urban, non-urban), costs of use and ownership of vehicles
Commuter survey	Employment activity	Location, frequency, flexibility, opportunities for telecommuting/compressed work weeks,
FACE TO FACE	Audit check	Information in trip/activity diary
	Choice experiments	commuter mode, alternative fuelled vehicles, commuter trip departure time
	Change response	Response to future scenarios - "what if.....". Contingent valuation (see notes), choice experiments
	Tech. propensity	Identify adaptation to new technology
	Residential choice	Dwelling type, proirities in choice, access
	Attitudes	Broad based attitudes to various policy instruments
	In service emissions	Willingness to participate in FORS study

An initial list of data items to be sought in each survey is summarised in Appendix B and schematically presented in Figure 10. The types of information collected from each survey can be summarised in broad categories. Table 4 above gave an overview of the information we propose to obtain. Details of the survey instruments will be developed in future task papers.

Figure 10. The Survey Strategy



Notes:

1. All of the necessary data to estimate the base revealed preference fleet size and auto type choice models can be obtained from the CATI survey (supplemented by external non-survey data sources).

6. CHOICE EXPERIMENTS

6.1 Stated Choice

The discussion of the set of vehicle, travel and location choice models above has assumed in the main that the alternatives under consideration and the attribute ranges in model estimation are currently observed in the market. Where instruments to be evaluated require evaluation of situations which are not observed in practice, we have to introduce a complementary set of choice modelling procedures designed to *enrich* the set of revealed behaviour models. Enrichment enables us to empirically derive a set of taste weights or parameter estimates which give a richer and more reliable meaning to mean parameter estimates where *new* alternatives are introduced and/or where existing attributes are *stretched* in application to levels beyond those observed in practice and which would otherwise be the range limits for model estimation and hence application. In this section we provide an overview of stated choice experiments which are the empirical basis for securing enrichment data and outline the choice contexts which will be subject to the design of choice experiments used to enrich the revealed preference (RP) models. As a lead into stated choice (SC) experiments, it is important to place their appeal in the more general context of behavioural choice models, which is independent of the nature of the choice response.

An individual when choosing amongst a set of mutually exclusive alternatives is assumed to identify the set of attributes relevant to the personal decision calculus, and will impose implicit weights on each attribute to arrive at a choice. The socioeconomic characteristics of the decision maker will have a conditioning influence on both the attribute weights and the determination of the feasible choice set. Although the individual decision maker knows precisely, although subconsciously, the decision calculus and the set of attributes used in arriving at a choice outcome, the analyst is not privy to this level of detail. Consequently the analyst has to try and explain the observed choice outcome, be it based on a market observation or a response to a stated choice experiment, with a component of the knowledge available to the decision maker summarised by an index of the unobserved influences.

In linking the observed and unobserved sets of attributes associated with each alternative to the choice outcome, it is generally accepted practice that individuals act as if they are maximising utility subject to a set of constraints. These constraints may be financial, temporal or physical. The solution to the utility maximisation problem is an indirect utility expression for each alternative which is a function of the observed and/or measured attributes of an alternative, a set of socioeconomic characteristics which are proxies for some of the unobserved attributes of an alternative, and a random effect to represent the residual set of unobserved attributes of the alternatives. The random utility model (RUM) provides the theoretical basis for the popular set of discrete choice models such as multinomial logit, nested logit and multinomial probit (Ben-Akiva and Lerman 1985, Hensher and Johnson 1981). Further details of the underlying properties of discrete choice models, applicable for both revealed and stated choice data are given in Appendix A.

The behavioural framework outlined is applicable for both RP and SC data. The definition of the observed and unobserved influences on the choice outcome however varies. First, the observed levels of the attributes of alternatives typically obtained in an RP study are sought directly from the decision maker or taken from exogenous data such as posted prices. The responses are reported perceived levels, which may vary from the "actual" levels. By contrast, the attribute levels associated with an SC study are fixed by the analyst, and are by definition "actual" levels. Thus we have at least one source of variation in the metric of the observed attributes of alternatives. Second, the choice outcome in the RP study is the known outcome, whereas for the SC study it is the potential outcome or the outcome with the highest likelihood of occurrence given the combination of attribute levels offered in an experimental replication. Third, the SC study elicits choice responses from a repeated measures experiment in which the attribute levels (and even the choice set) are varied, in contrast to the single response in an RP study. Thus there is a greater amount of information on decision maker response to a range of possible attribute profiles.

After recognising the likely sources of observed variation between RP and SP data, the remaining unobserved sources of indirect utility are most unlikely to display identical distribution profiles within the common sampled population. Hence the "naive" pooling of the two types of data cannot be treated as if they display identical unobserved effects. Given that the variance of the unobserved effects is an important piece of information used in the derivation of the functional form of a probabilistic discrete choice model (McFadden 1981), this variance deviation has to be recognised and accommodated. One solution proposed originally by Morikawa (1989) is to scale the variance of the unobserved effects associated with the SP data so that the equality of variances across the RP and SP components of a pooled model is reinstated. The indirect utility expressions are defined as:

$$\begin{aligned} V_{rp} &= \alpha + \beta X_{rp} + \psi Y + \varepsilon_{rp} \\ V_{sp} &= \delta + \beta X_{sp} + \gamma Z + \varepsilon_{sp} \end{aligned} \quad ; \theta^2 = \mathrm{var}(\varepsilon_{rp})/\mathrm{var}(\varepsilon_{sp})$$

where

X_{rp}, X_{sp}= a vector of observed variables common to rp and sp data
Y, Z = vectors of observed variables specific to one data set or the other

$\beta, \alpha, \delta, \psi, \gamma$ = unknown parameters

$\varepsilon_{rp}, \varepsilon_{sp}$ = the unobserved effects associated with the rp and sp data configurations

θ^2 = the scaling parameter, enabling the scaling of V_{sp}' equal to θV_{sp}, and hence joint estimation of the two data sets.

The probability of a decision maker selecting an alternative out of the available set of alternatives is defined as the probability that the observed and unobserved indirect utility of an alternative is greater than or equal to the observed and unobserved indirect utility of each and every other alternative in the choice set:

$$\text{Prob}_j = \text{Prob}\{(V_j+\varepsilon_j) \geq (V_{j'}+\varepsilon_{j'}); j \in J; j \neq j'\}$$

Particular assumptions on the distribution of the unobserved effects within the sampled population lead to a particular functional form of the discrete choice model (see Appendix A). A priori the relative magnitudes of the variances is unknown, due to the many sources of differences between the RP and SC contexts. The equality of variances is a permissible empirical outcome, but not one to be assumed ex ante.

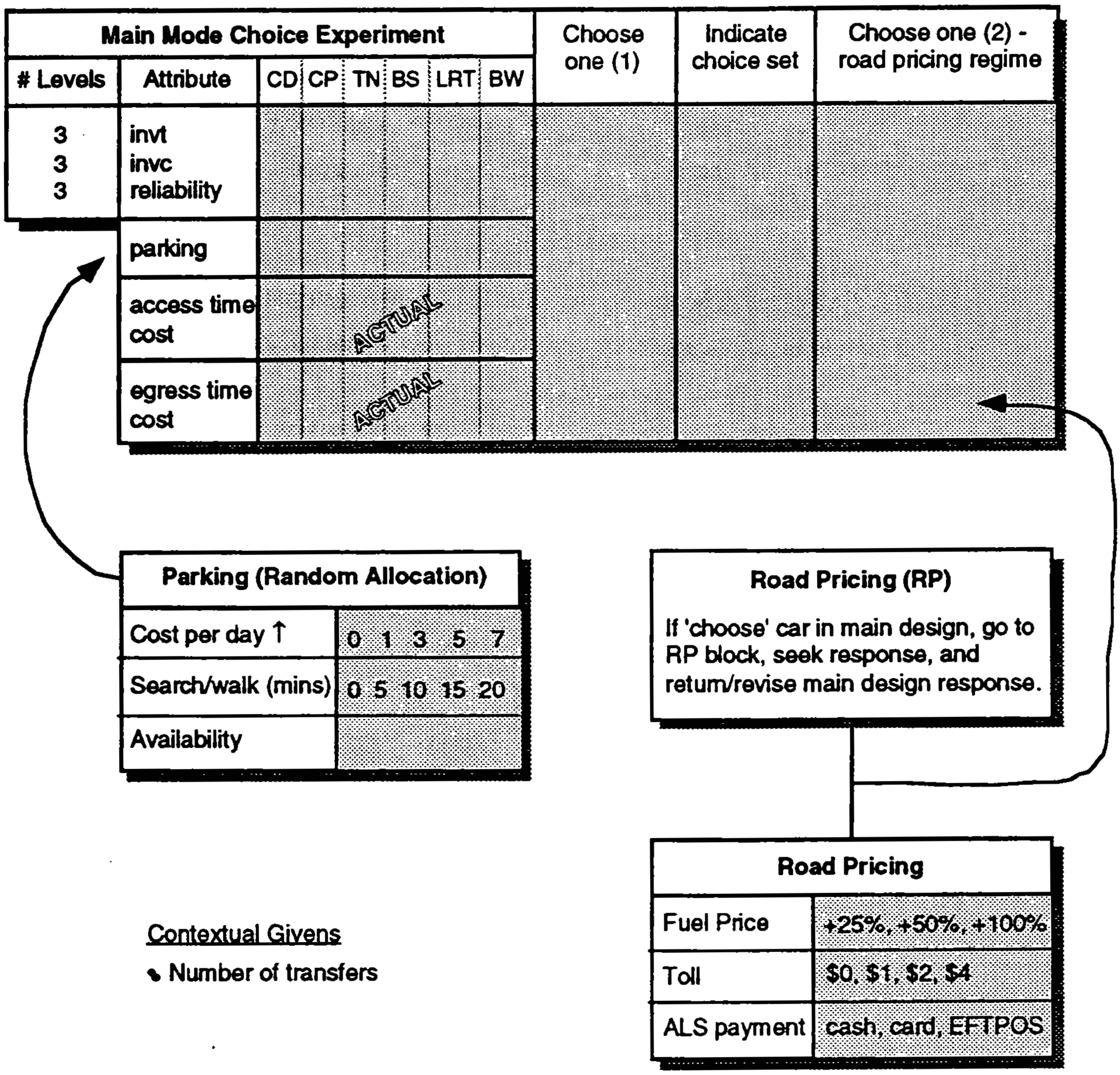
An appealing feature of stated choice (SC) data is the ability to view the experiment as the stated response counterpart to revealed preference (RP) data, the mainstay of econometric modelling. In addition to the capability of stated choice experiments to extend evaluation beyond observed attribute levels, the essential difference is one of scale. The recognition of the relative strengths and weaknesses of both types of data suggest that the joint utilisation of both data should enrich the modelling activity and further our understanding of choice behaviour. In particular SC data can be used effectively to enrich the predictive capability of a base RP model, especially where the market share for a new alternative is being evaluated.

Whereas RP data describes actual choices in terms of a set of market-based measurements of attributes of alternatives (which by definition are restricted to the currently available feasible set), the SC data describe potential choices in terms of a set of constructed measures of combinatorial mixes of attributes of real and/or hypothetical alternatives. The opportunity to position an SC data set relative to an RP data set within the one empirical analysis on the common choice problem enables the modeller to extend and infill the relationship between variations in choice response and levels of the attributes of alternatives in a choice set, and hence increase the explanatory power of the RP choice model.

The mixing of sources of data however is not a matter of "naive" pooling. It requires careful consideration of the unit of the (indirect) utility scale. For example, the utility scale in an MNL model is inversely related to the variance of the unobserved influences, summarised as the random error term; hence the parameter estimates of two identical indirect utility specifications obtained from two data sources with different variances will necessarily differ in magnitude, even if the choice process that generated the indirect utilities is identical. The notion of scaling is not new. Horowitz (1981), for example, alluded to it. However prior to the contribution of Morikawa (1989), the scaling discussion was not specifically directed to the opportunity to enrich RP data with SC data. Some recent applications using mixed data are Morikawa (1989), Bradley and Daly (1991, 1992), Hensher and Bradley (1993) and Swait and Louviere (1993).

An example of the type of stated choice experiment which relates to a number of possible behavioural responses is set out below (Figure 11). In this commuter mode choice example, the respondent is asked to provide details of the access and egress legs of a trip, as well as parking. The attribute levels of the linehaul part of the trip by the main mode form the attribute combinations derived from a fractional factorial experimental design. The design aspects of choice experiments will be detailed in task paper T5. A commuting respondent is asked to consider a scenario of main mode attribute levels for each alternative mode and to choose one. The respondent is also asked to indicate which of the alternatives in the full choice set they evaluated as serious options. Where the chosen mode is car (either as a driver or passenger), the respondent is asked to go to the road pricing experiment, in which a randomised combination of changes in fuel prices, tolls and method of payment are indicated as the financial obligation when using the car for the commuter trip. In the current study we will develop this as a financial package in line with the arguments developed in section 2. The respondent will be asked to review the original choice and to revise it if necessary. A savings in travel time will be offered as a benefit of paying the toll. The original and the revised choice responses provide important information on the individual's propensity to choose a mode and to switch modes for the commute trip in the absence/presence of different road pricing scenarios. The choice experiment can be repeated with the same respondent, varying the attribute levels and seeking further choice responses. Choice experiments need not be conducted sequentially and conditionally, they may be designed for simultaneous treatments, where some combinations of attribute levels have no road pricing, while others do, and both are assessed at the same time. Whether a sequential approach is more realistic is an empirical question still to be resolved. The stated choice experiment provides a rich framework for mapping out behavioural responses in utility space in evaluating a large number of instruments capable of reducing GGEs.

Figure 11. An Illustrative Choice Experiment



Note:

(i) Each road pricing scenario will be accompanied by an endogenously determined travel time, derived from a model of the form: travel time = f(travel cost, road price, OD modal split, residential density for the SLA.....). This endogenous travel time equation is necessary as a proxy for the impact at a strategic level of how network travel times change in the presence of a travel pricing shock.
(ii) The cost per day for parking can be changed to allow for the time of day a person arrives at a parking station. This variation is designed to encourage a reduction in peak road congestion.

6.2 Contingent Valuation

The contingent valuation method (CVM) has been applied with increasing frequency to the measurement of environmental policy benefits and damage costs. CVM uses a direct approach - it basically asks people what they are willing to pay for a benefit, and/or what they are willing to receive by way of compensation to tolerate a cost. What is sought are the personal valuations of the respondent for increases or decreases in the quantity of some good, contingent upon an hypothetical market. Respondents say what they would be willing to pay or willing to accept if a market existed for the good in question. A contingent market is taken to include not just the good itself (an improved view, better water quality, etc.) but also the institutional context in which it would be provided, and the way in which it would be financed. One major attraction of CVM is that it should, technically, be applicable to all circumstances. CVM has two important features:

- It will frequently be the only technique of benefit estimation;
- It should be applicable to most contexts of environmental policy.

The aim of the CVM is to elicit valuations - or "bids" - which are close to those that would be revealed if an actual market existed. The hypothetical market - the questioner, questionnaire and respondent - must therefore be as close as possible to a real market. The respondent must, for example, be familiar with the good in question. If the good is improved scenic visibility, this might be achieved by showing the respondent photographs of the view with and without particular levels of pollution. The respondent must also be familiar with the hypothetical means of payment - say a local tax or direct entry charge - known as the payment *vehicle*.

The questioner suggests the first bid [the "starting point bid (price)"] and the respondent agrees or denies that he/she would be willing to pay it. An iterative procedure follows: the starting point price is increased to see if the respondent would still be willing to pay it, and so on until the respondent declares he/she is not willing to pay the extra increment in the bid. The last accepted bid, then, is the maximum willingness to pay (MWTP). The process works in reverse if the aim is to elicit willingness to accept (WTA): bids are systematically lowered until the respondent 's minimum WTA is reached.

Designs of CVM questionnaires vary. Respondents may be given hypothetical budgets to allocate between expenditures, or they may be told about the bids made by other respondents. The variability in the design is useful because it permits some testing of the relevance of including certain types of information and constraints. Thus, knowing how others have responded enables the individual to change his bid, thus testing for so-called "strategic bias" in responses. Approaches with such information may then be compared to approaches without that information.

7. THE FORECASTING STRATEGY AND "MARKET" POTENTIAL

The primary objective of the study is to provide forecasts of the change in greenhouse gas emissions which might result from the application of the range of instruments summarised in Table 1. Under various strategies involving a combination of instruments at various strengths, the percentage change in GGEs and the associated marginal and total cost can be predicted. In assessing the impact of various strategies, we have to place them within a time path up to the year 2015, using a number of cut-off points to measure the accumulated contribution to date. The cut-off years are 1996, 2000, 2005, 2010 and 2015.

Forecasting is a complex process, with inherent uncertainties. Any forecast must be more than a mean estimate, it must have a range directed by confidence limits reflecting uncertainty. The uncertainty arises because of the extension of a modelling framework beyond the level of knowledge based on observation of actual behaviour and behavioural response. The use of stated choice experiments is an important aid in reducing some aspects of uncertainty - it provides us with an interpretation of possible future behavioural response based on each individuals current experience and appreciation of new opportunities as expressed through an instantaneous choice experiment. There are however uncertainties external to behavioural response; primarily associated with demographic and socioeconomic forecasts of the composition of future populations. These exogenous forecasts are a potentially major source of error through uncertainty which are predominantly beyond the control of the study team. Other sources of forecasting error due to uncertainty include the manufacturers indications of the timing of the introduction of new energy-based vehicle technology, and the role of bandwagon effects as communities accumulate experience and exposure to new products.

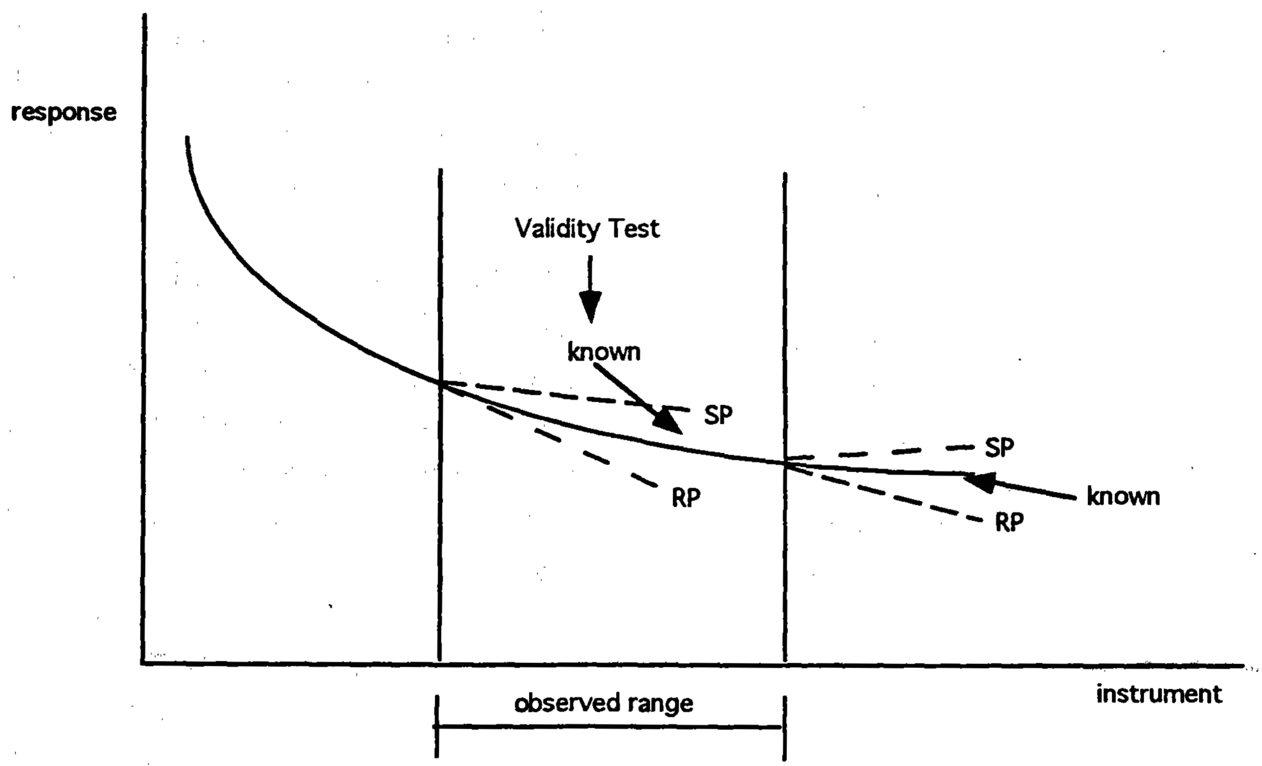
A preferred nomenclature in assessing the future is market potential. Any 'forecast' is best thought of as an indication of the potential to achieve an outcome. Yet it is made at the current time, and is unable to account for all the possible intervening influences on the path along the way to the forecast year. An essential input into maximising the probability of securing the forecast outcome is sustained marketing of the set of strategies which have been applied to produce each forecast. In addition, an ability to revise the inputs into the forecasted output is essential as one recognises sources of error ex post.

In the current study we will undertake extensive testing of the base models to ensure that they have the necessary external validity for implementation beyond the base year. To illustrate a procedure for evaluating the external validity of the base year model system, estimated with revealed preference data enriched by stated choice data, one knows the market response under the existing levels of attributes identified as statistically significant influences on travel behaviour and vehicle choice. In Figure 12, we schematically depict the relationship between an RP-based prediction, an SC-based prediction and then observed response. The application of the stand-alone SC choice model with the observed levels of the attributes of the alternatives in the choice set will produce one set of predictions to compare with observed behaviour; the same procedure with the RP choice model will produce another set of predictions. Both are likely to deviate from actual behaviour. Since we know the actual behaviour within the base year, we have one test of external validity. Calibration then follows estimation to adjust the model to reproduce the relevant base shares.

This test of external validity is a *local static* test. An additional test with great importance is a local *change* test. A model capable of reproducing static (i.e. equilibrium) shares may not be as reliable in predicting shares after a change brought on by a strategy. One has to draw on a combination of "commonsense" and evidence from other studies, predominantly empirical estimates of elasticities. There is always an element of risk in relying on previous studies since this be definition imposes a rule of conforming with the past. If this rule were some important, then the need for studies such as the present study would be considerably discounted.

Ultimately, care and attention to detail and assumptions within the current study will be the main guiding force in the acceptability of the forecasts as the best evidence currently available.

Figure 12. Issues of External Validity



8. THE ITS-BTCE STRATEGY SIMULATOR

All of the conceptual, modelling and empirical elements of the study will packaged initially as a PC-based (and later as a Macintosh-based) software system. The architecture of the software is summarised in Figure 13. The software is modularised as follows:

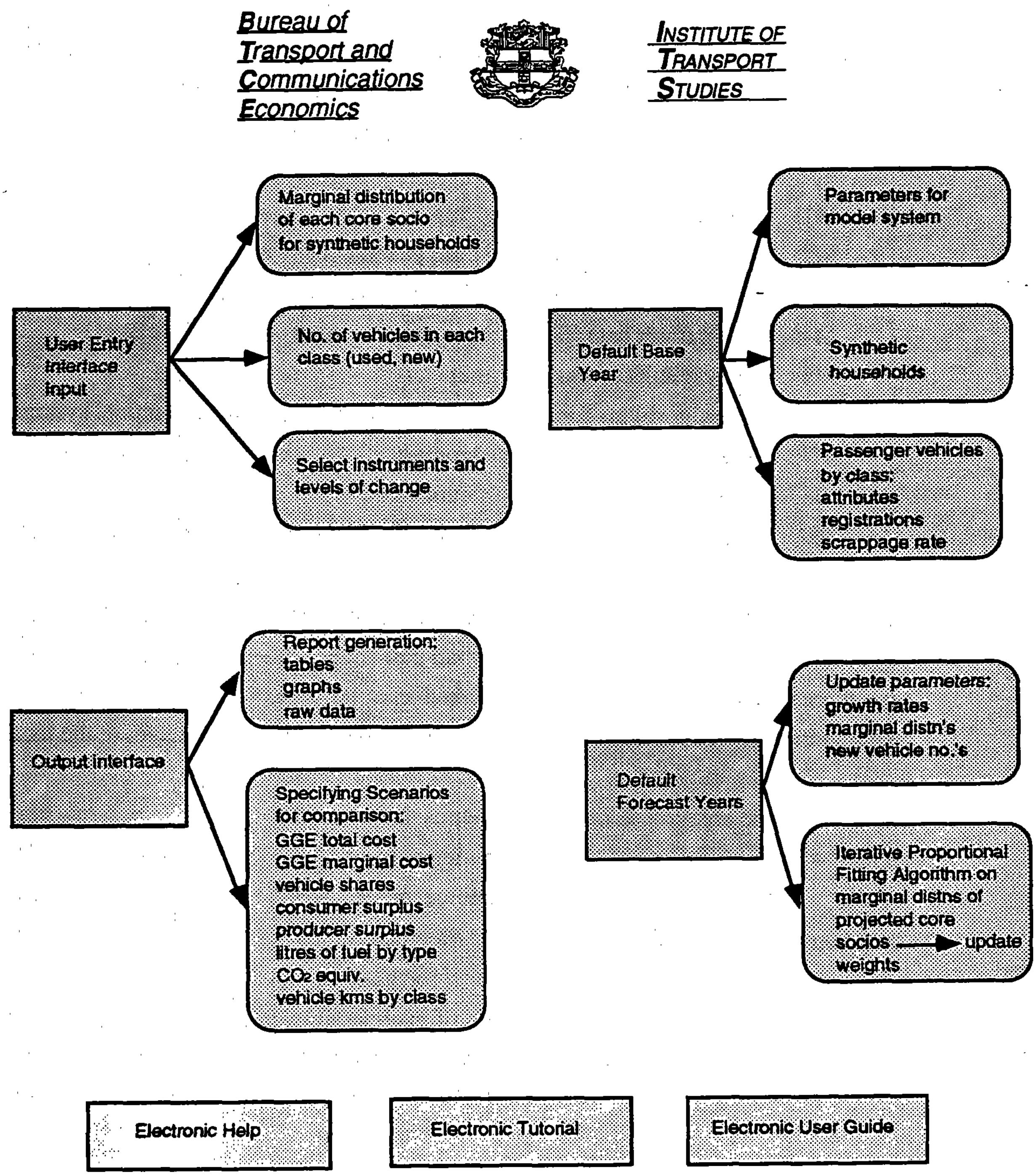
- M1: The user entry interface
- M2: The default parameterised base year model system
- M3: The default data file for base year synthetic households
- M4: The default data file for base year passenger vehicles by class
- M5: The default forecasting parameters
- M6: The algorithms for projecting exogenous inputs into the model system
- M7: The output interface to generating reports tables, graphs and raw data
- M8: The help and tutorial instructions
- M9: A user guide which can be consulted electronically at each stage of use

The architecture of the simulator will enable applications to be undertaken to assess the impact on global climate of a large number of urban passenger transport related strategies. It will also have the capability in the future to be linked in at the local air pollution level with transport planning tools such as EMME/2 to evaluate the impact of network changes at the local level.

The user will be able to use pull-down menus to select one or more instruments to evaluate for each urban area. A full set of default parameters for the base and forecast years will be provided for the vehicle, travel and location choice models, vehicle use models, and the vehicle scrappage model. In addition the appropriate data to define the synthetic households and the vehicle classes will be provided as defaults. Each user can, if they wish, change the parameters of the equations, the base attribute levels of each vehicle class and each synthetic household, including the population weights. The model system will use the marginal distributions for the core socioeconomic variables plus a knowledge of forecast population totals to revise the synthetic weights through time.

To give an appreciation of how the simulator might operate, let us take one strategy and work through the logic of the operations. The user will pull down a selection menu of instruments. Having selected one or more instruments, the user is asked to define percentage and/or absolute changes for each instrument. This then becomes the strategy. The user then goes to the forecasting module via the menu where the forecast years are selected together with the choice of outputs required from a long list of options. One can select all outputs (lots of pages). The mode of presentation for each option is also requested (table, graph, other). Upon exiting the

Figure 13. The ITS-BTCE Strategy Simulator

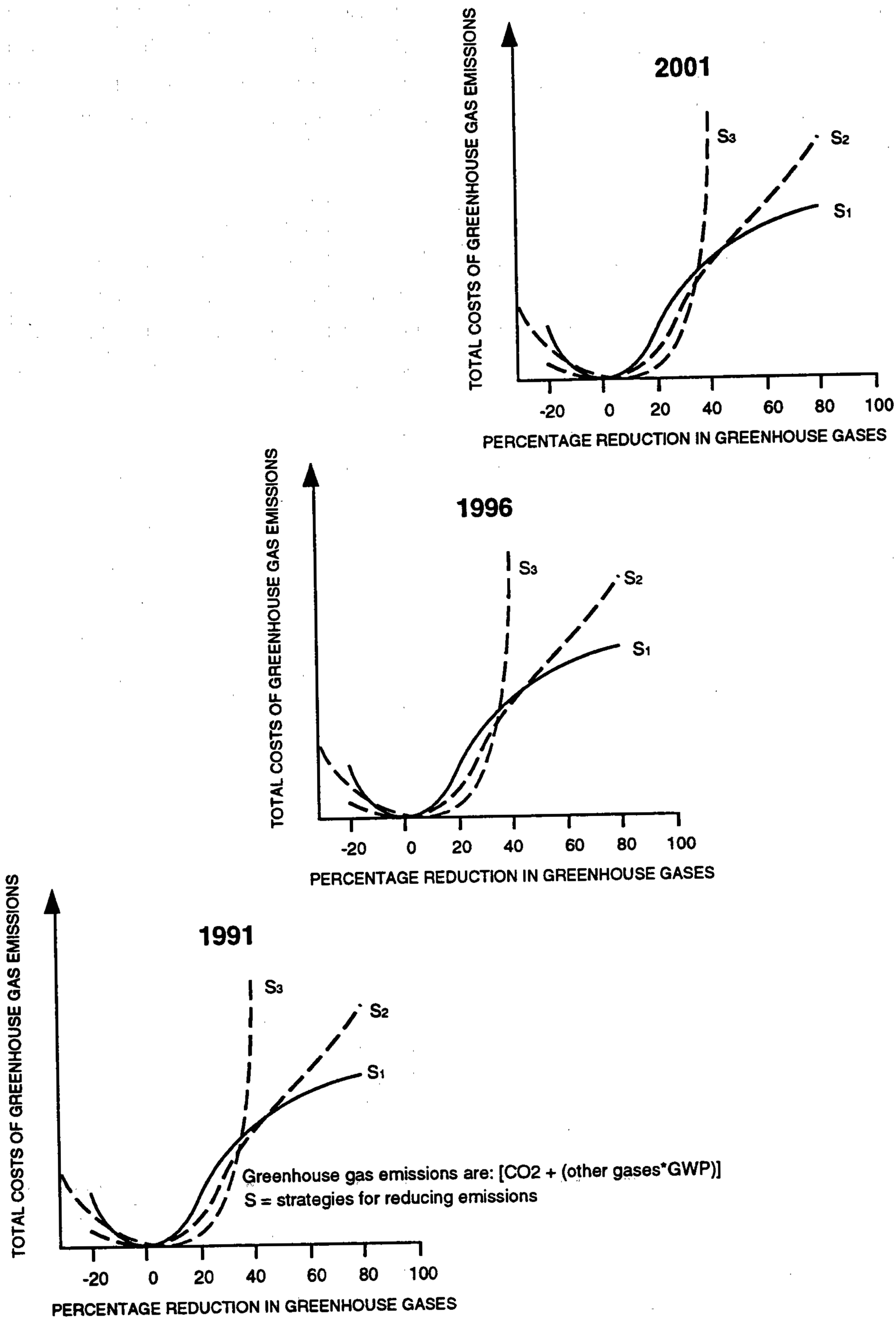


output menu one is asked if a change in any of the input modules is required. If no, the set of default parameters are selected, and the simulator will then run. All output is sent to an output file as well as being retrievable for immediate display on the screen.

If a user wishes to change any input parameters, then the input menu is called and a number of sub-modules are each called upon to enable changes. The set of change options include (i) the parameters of each travel, vehicle, location choice model, and the vehicle use models (ii) the incidence of population households represented by each synthetic household (iii) the profile of new vehicles by class, (iv) the scrappage rates for classes of vehicles by vintage, (v) the attribute levels of the base year which will not be changeable from the menu used to select strategies and (vi) a change in the supply of housing (i.e. density profile) by type and location (i.e. SLA).

The user is given an output menu enabling a selection of reports and their presentation format. Included in the outputs will be graphs of the total and marginal costs associated with percentage changes in greenhouse gases due to particular strategies (Figure 14), measures of change in consumer surplus, producer surplus, vehicle kilometres, vehicle emissions, energy consumed etc. As the study evolves more detail will be provided of the design of the simulator.

Figure 14. Final Output Format (accumulated over time and by year)

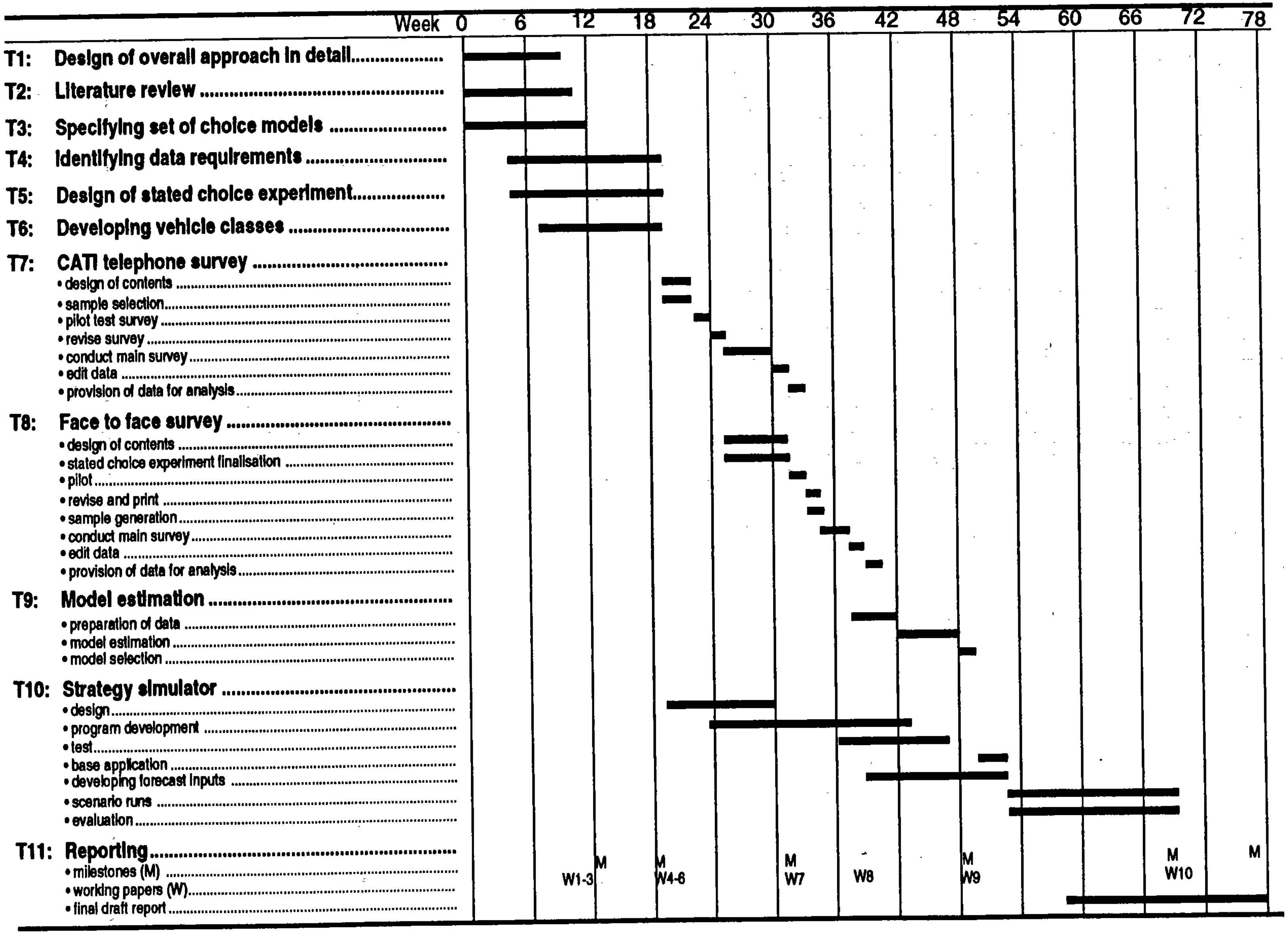


9. CONCLUSION: REPORTING AND DOCUMENTATION STRATEGY

This overview report provides the architecture for the development and execution of the entire study designed to evaluate strategies for reducing greenhouse gas emissions in the urban passenger transport sector. The timing of the overall study is summarised in Figure 14, with a commencement date of August 9, 1993. Each major topic discussed in this report will be given a more detailed treatment in further task reports T3-T11.

To ensure that the information collected in this study is available in the future in a readily accessible form, we propose to prepare a major documentation report, accessible on the electronic medium. The most important information in this document will be details of each vehicle on the road (attributes, registrations, prices, scrappage rates in each year from 1991 onwards), the profile of synthetic households in each urban area with population weights for each year from 1991 onwards, assumptions in forecast years on all exogenous variables used to move the sampled population (both households and vehicles) forward in time, and the original fully edited survey data collected as part of this study. Together with the ITS-BTCE strategy simulator, all the necessary information is available to maintain the forecasting activity, and to facilitate cost effective updates from time to time.

Project Tasks and Timeline



Appendix A. Discrete-Choice Modelling: A Brief Overview of the Underlying Theory

The formulation of the complete set of vehicle, travel and location choice models is guided by an underlying theoretical framework centred on the behavioural postulate of utility maximising behaviour. Each exogenously sampled individual in a household is assumed to evaluate alternatives in a choice set on the basis of the attributes of each mutually exclusive alternative, and to choose the alternative which gives the highest level of utility. Although each individual decision maker is assumed to have complete knowledge of the relevant set of attributes influencing a choice outcome, the analyst has available through observation and measurement only a partial set of the relevant attributes. Consequently, all choice modelling is constructed on the modified assumption of random utility maximisation. Thus we can at best assign a probability to an individual choosing an alternative out of a choice set. To give an appreciation of how this theoretical framework is translated into a behavioural choice rule and implemented through an empirically estimable choice model, we will use the example of commuter mode choice.

Consider a two-level commuter mode choice decision involving two choice sets: the generic choice set (G) of private and public transport, and the elemental choice set (M) of car drive alone, car drive accompanied, train and bus. The indirect utility function associated with an elemental mode m contained within the generic category g is given in equation (A1).

$$U_{gm} = U_g + U_{m|g}, \quad m \in M_g, \quad g \in G \qquad \text{(A1)}$$

where U_{gm} is the joint probability of choosing alternative m conditional, on the probability of choosing alternative g, $U_{m|g}$, and the marginal probability of choosing alternative m.

The hierarchical structure is given in Figure A1. The standard multinomial logit (MNL) model assumes that the ratio of the selection probabilities of any pair of modes is independent of any other mode(s) - that is, equality of all cross-elasticities, and so we can collapse the model structure into a single-level specification. This condition is associated with the assumption that the unobservable components of the indirect utility expression for each alternative are independently and identically distributed (IID). Hierarchical structuring is a mechanism for decomposing the single choice into sub-choices or clusters such that the MNL condition need not hold *between* clusters. It is assumed to continue to hold within a cluster.

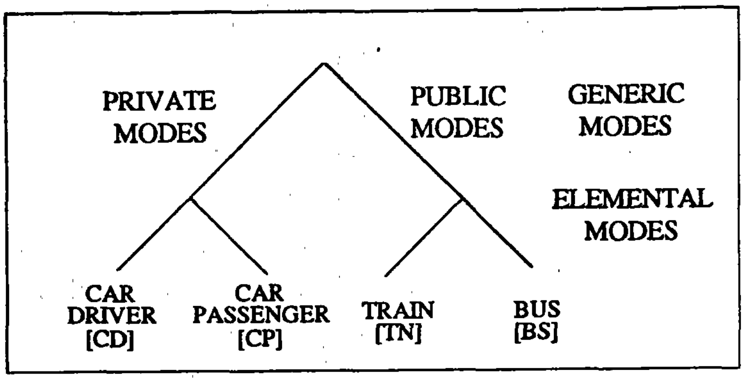


Figure A1. An Hierarchical Modal Structure

Let us write the U_{gm} expression in terms of component vectors for the observed (V) and unobserved (μ, ε) influences on choice:

$$U_{gm} = V_g + V_{m|g} + \mu_g + \varepsilon_{m|g}\ ,\ m = 1,\ldots, M_g,\ g = 1,\ldots,G \qquad (A2)$$

and define the variance-covariance matrix for the unobserved effects in terms of the associated elements

$$\Sigma_{gm,\ g'm'} = E\ [(\mu_g + \varepsilon_{m|g})*(\mu_{g'} + \varepsilon_{m'|g})]. \qquad (A3)$$

Invoking the independence assumption of the distributions in the two choice dimensions and random utility maximisation, numerous authors (e.g. McFadden 1981, Williams 1977, Hensher and Johnson 1981) have shown that the joint probability of choosing alternative *gm* can be defined as equation (A4), a hierarchical logit model:

$$P_{gm} = \frac{\exp[\lambda(V_g+V_{g*})]}{\sum_{g'\in G} \exp[\lambda(V_{g'}+V_{g'*})]} \frac{\exp[V_{m|g}]}{\sum_{m'\in M_g} \exp[V_{m'|g}]} \qquad (A4)$$

where

$$V_{g*} = I_{g*} = (1/\lambda) \log \sum_{m'\in M} \exp[\lambda_{m'|g}] + \text{eulers's constant.} \qquad (A5)$$

A global sufficiency condition for the hierarchical or nested choice model in equation (A4) to be consistent with random utility maximisation is that the coefficient of the inclusive value index I_{g*} be in the 0-1 range (McFadden 1981). Under a local sufficiency condition proven by Borsch-Supan (1985), the parameter of inclusive value can be permitted to exceed unity. The parameter(s) of inclusive value(s) provide the basis for differences in cross-substitution elasticities as compared to the IID condition of MNL.

The majority of mode choice models estimated as a nested logit model use sequential estimation. This involves firstly the separate estimation of each choice situation as the lowest level in the hierarchy - CD vs CP and TN vs BS in Figure A1, then the calculation of inclusive values I_{g*}, followed by estimation at the upper level(s). Because separate models are estimated on each branch at the lower level, there is potential for a considerable loss of information. This affects both the sample size and the distribution of the levels of the exogenous variables. Clearly one can only include in the lower level estimation those observations which have a chosen mode and at least one alternative in that branch. In reality, mode choice observations typically have varying choice sets containing the chosen mode in one branch and the non-chosen mode(s) in another branch (Hensher 1986). Sequential estimation is statistically inefficient in that the parameter estimates at all levels above the lowest level do not have minimum variance parameter estimates. This is the consequence of using *estimates of estimates* in the calculation of the contribution of aggregate utility or inclusive value indices of the subsets of alternatives below the relevant node. Inclusive values are not relevant for a degenerate node - a node with a choice set of one. Correction procedures to obtain asymptotically efficient estimates from sequential estimation are extremely complex (McFadden 1981), especially for more than two levels, although they are automated in the LIMDEP software package. It is also inefficient because the task of calculating inclusive values and relating them to the upper level is quite demanding.

The literature gives the misleading impression that sequential nested logit modelling requires less data than simultaneous MNL. For example with 6 departure times and 4 modes there are 24 mode by departure time combinations of data required to estimate an MNL model whereas a nested logit model of mode given departure time requires 4 data points for each individual and departure time choice requires up to 6 data points. However the calculation of inclusive value requires data points for all modes to all departure times in the choice set regardless of which departure time is chosen. The ultimate saving in data is zero. The gains in nesting are linked to the variation in cross-alternative substitution.

The presence of degenerate nodes at the lower level also requires that data on such alternatives be included in the upper levels but not via inclusive values. This creates problems in interpretation, especially where a variable can appear in more than one level (Hensher 1986). Furthermore, if theory argues for certain conditions on the parameters of particular variables, such as the equality of cost coefficients throughout the structure (Truong and Hensher 1985), this cannot be accommodated in total - it can be handled within a level by stacking such that each branch is treated as a separate observation. This however forces an unranked and hence generic specification on all explanatory variables. Alternative (type)-specific constants can however still be calculated for types of alternatives contained in each alternative in the unranked set.

Full information maximum likelihood (FIML) estimation avoids the problems of sequential estimation, but does require somewhat complex software. Software packages are currently available for FIML nested logit modelling. FIML also introduces some new issues. First the hierarchical (HL) model as a set of independently estimated MNL models has a unique optimal solution and no local sub optimal maxima for the likelihood function. FIML-HL however must have a unique optimal solution, unless there is a lack of identification, but there may be local sub optimal maxima. Great care must be exercised in the selection of starting values for all of the parameter estimates. Second, the optimisation procedure will accept analytical first derivatives, and analytical second derivatives but the latter are not available in simple form. Thus the practice has been to accept either approximate analytical second derivatives (Small and Brownstone 1981, Hensher 1986) or numerical second derivatives (Borsch-Supan 1984). Given the highly non-linear behaviour of the parameters of inclusive value, use of the first derivatives only is not recommended.

The full log-likelihood expression for a FIML hierarchical model extended to three levels is of the form:

$$\log L = \sum_{q=1}^{Q} \sum_{m \subseteq (1,\ldots,M)} S_{mq} \log \left[P(m \mid x_m, \beta, \theta, \lambda) \right] \tag{A6}$$

where $q=1,\ldots,Q$ observations, $m=1,\ldots,M$ modes, θ and λ are the parameter estimates of inclusive value for the top and middle levels, S_{mq} equals 1 if mode m is chosen and zero otherwise, x_m are the set of other explanatory variables, and their parameter estimates.

For a three-level logit model of the form:

$$P_{agm} = P(a) * P(g|a) * P(m|a,g), \tag{A7}$$

the joint cumulative distribution function of the errors is (McFadden 1981,1984):

$$F(\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_z) = \exp\{-G[\exp(-\varepsilon_1),\ldots,\exp(-\varepsilon_z)]\} \tag{A8}$$

with

$$G(y_1,\cdots,y_z) = \sum_{a} \left[\sum_{g' \in a'} \left(\sum_{m' \in g'} y'^{1/\lambda}_{m} \right)^{\lambda/\theta} \right]^{\theta} \tag{A9}$$

where we sum over the highest level containing alternative a', the subsets of alternative gm contained in each branch of the top level, and then over the elemental alternative m' in each of the middle level branches. Model form (A4) is applied in the empirical studies for the set of discrete choice models of the logit form.

Appendix B. New Surveys: Preliminary Indication of Data Requirements (Finalisation of question placement will evolve during the study)

PART A - CATI SURVEY DATA REQUIRED:

Location of household will be identified by the telephone number. The telephone number would then be used to identify each part of the survey as belonging to that household.

1. Number and type of vehicles used by that household, ranked by length of time in the household:
   - Cars
   - Motorbikes
   - Light vans

2. Details of motor vehicles
   - Make
   - Model
   - Year of manufacture
   - Year of acquisition
   - Body type (sedan, hatch, wagon, panel van, ute)
   - CC's/turbo
   - No. of cylinders
   - Transmission
   - Air conditioning
   - Fuel type used
   - Registration
   - Ownership - private/business, exclusive ownership (use) within household

3. Some general questions on the knowledge and perceptions of respondents of the GGE problem and the use of alternative fuels in motor vehicles. This would be useful in assessing the level of community awareness and need for educational programs. They would also be useful in "softening up" the respondent. People tend to become suspicious if only hard factual data on their household composition etc. is asked, especially over the telephone. A few attitudinal questions would be useful in establishing a rapport with the respondent in order to obtain the factual data. Some suggested examples might be:

   What do they know about a range of alternative fuels?

Are they aware of the problem of GGE ?

What do they understand is meant by GGE and their implications for the environment?

4. Number of persons who permanently live at that address:
(Ranked by age)
   Age
   Sex
   Employment status/student
   Drivers licence
   Relationship within the household

5. Request address and permission to mail out one-day diaries and to participate in the face to face survey.

PART B - MAIL OUT SURVEY

Mail out to all CATI respondents a one day trip diary for each member of the household, days sampled randomly across the 7 day week, also a commuter questionnaire for each person in the household in full time or part time employment or who is a full time student, and a household vehicle questionnaire.

1. ONE DAY TRIP DIARY

Details collected of the trips made by each person on the sampled day to include, for each trip made:
   Origin
   Start time
   Mode of travel (must include details of any travel with other members of the household and if relevant, which of the household vehicles was used)
   Reason for travel
   Distance travelled
   Destination
   Arrival time
   Cost of trip

Diary must be carefully designed to ensure that all details of trip linkages, multipurpose trips and interrelationships of that household member's trip with those of the other members of the household e.g. undertaking other activities as part of the commute trip, shopping, dropping off other household members etc., are collected.

2. COMMUTER QUESTIONNAIRE

Employment type, occupation, position

Work place /place of education for each person

Frequency of attendance
Start and finish times
Participation in and constraints on working flexitime, compressed work week, telecommuting
Mode of travel - car as driver, car as passenger, train, bus/train, car/train, bus, motorbike, bike, walk, other
Time and cost of mode used
Alternative modes/ which ones have been tried and why were they abandoned/perceptions or knowledge of time and cost of these options.
Parking availability and cost

Change of mode or work time scenario questions. For example "what if household member 1 did not use/did use public transport for the journey to work, how would that affect the travel patterns of other members?" What is the impact on vehicle use if one member of the household works a compressed work week or telecommutes?

Reactions to a broad range of policy options and lifestyle changes.

3. HOUSEHOLD VEHICLES QUESTIONNAIRE

For each vehicle in the household information to be collected on:

Total number of kilometres travelled over the past 12 months
Kilometres travelled - percentage non-metropolitan and metropolitan and metropolitan kms by trip purpose
Running costs - insurance, registration, maintenance - responsibility for payments
Maintenance pattern

PART C - FACE TO FACE INTERVIEW

1. Check any missing data from CATI interview and trip diary.

2. Residential location choice:
   - Type of dwelling
   - Occupancy status
   - Length of time in the dwelling/general area
   - Reasons for location choice
   - Access to public transport and CBD

3. Experiment questions:
   - New vehicle technology, alternative fuels (auto type choice)
   - Taxation/pricing policies
   - Propensity to change household location/place of work
   - Commuter mode choice

4. Other household socio-economics

Household income

Appendix C. Specifying a Vehicle Scrappage Model

The first task if to identify a suitable form for the loss rate model. Given the hypothesis that vehicle price is an important influence in the vehicle scrappage decision, we assume that the vehicle loss rate is a linear additive function of vehicle price as well as other vehicle attributes as embodied in the proxy dimensions of vintage and make. The relevant price is an equilibrium price, which must be identified as an hedonic-adjusted price, derived after controlling for quality differences embodied in such attributes as vehicle make, vintage, age, weight, body type and country of manufacture:

$$\hat{P}_{mat} = \kappa_0 + \sum_{b=1}^{B} \kappa_b [BT]_{bm} + \sum_{c=1}^{C} \kappa_c [CM]_{cm} + \sum_{k=1}^{K} \kappa_k X_{kmat} \tag{C1}$$

where BT_{bm} is the b^{th} body type (e.g. sedan) of model type m; CM_{cm} is the c^{th} country of manufacture of model type m; X_{kmat} is the k^{th} attribute of vehicle type m of age *a* in year t; and κ_0, κ_b, κ_c and κ_k are unknown parameters.

The role of economic characteristics of vehicles as embodied in price has two sources of variation - the variation through time for a vehicle of a particular make and model and the intra temporal variation across different makes, models and vintages. The intra temporal effect is likely to be the major source of the price effect on vehicle loss rate. The current price structure of the vehicle stock can be viewed as reflecting, in part, historical rates of inflation. We also assume that the (unknown) probability of scrapping a particular make-model-vintage vehicle can be equated with realised loss rates.

The probability of vehicle loss is a conditional probability. That is, it is the probability of a vehicle being scrapped given that it was on the vehicle register at the beginning of the period. Simplify notation by replacing *mat* with u, the probability of loss of vehicle v is given as:

$$\text{Prob (loss)}_\upsilon = \Phi_\upsilon [1 - F_\upsilon (P_\upsilon - R_\upsilon)] \tag{C2}$$

where Φ_υ is the exogenous *failure* distribution representing the probability of failure of vehicle v, and F_u (.) is a cumulative distribution function which gives the probability of a failure costing less than the costs of maintaining a vehicle up to a level to prevent it from leaving the market. The effect of premature vehicle scrapping due to collisions and other catastrophic causes such as theft for parts are embodied in equation (C2). The endogenous variable in (C2) is discrete, the log of the realised loss rate, whereas the functional form is a continuous function. The two sides of the equation are brought into line by integrating the *failure* probability density function over a suitable interval. We assume that h and F have the functional forms given in equations (C3) and (C4).

$$F_\upsilon (C_\upsilon) = 1 - \exp[(\kappa + \eta_\upsilon) C_\upsilon] \tag{C3}$$

$$\Phi_\upsilon = \exp\left[\beta_0 + Z_\upsilon \beta + \varepsilon_a + \mu_m\right] \tag{C4}$$

η_υ is a random effect for specific vehicle v, ε_a (μ_m) is a random effect for vintage-specific (model-specific) vehicles, C_u is the required cost of maintaining a vehicle model m of vintage a at time t with means varying randomly across vehicles, Z_u is a vector of vehicle characteristics (including age, vintage and make), and k, b_0 and b are unknown parameters. Scrappage occurs if $P_u - R_u < C_u$.

Substituting into equation (C2) and assuming that η_υ and ε_a are bivariate normally distributed with mean 0 and covariance = W gives the final loss model, equation (C5) for any vehicle v.

Prob (loss$|X_u, P_u, b, \varepsilon_a, m_m$)

$$= \exp\left[\beta_0 - \kappa R_\upsilon + 0.5\, \sigma_\eta^2 R_\upsilon^2 - \sigma_\varepsilon R_\upsilon + Z_\upsilon \beta - \left(\kappa + \sigma_\varepsilon - \sigma_\eta^2 R_\upsilon\right) P_\upsilon + 0.5\, \sigma_\eta^2 P_\upsilon^2 + \mu_m\right] \tag{C5}$$

Reinstating the model and time subscripts as well as simplifying equation (C5) by collecting terms, redefining the unknowns and assuming a zero scrap value, we obtain the estimable form of the loss model, given as equation (C6).

$$\text{Prob}\,(\text{loss})_{mat} = \exp\left[\tau_0 + Z_{mat}\, \beta - \tau_1 P_{mat} + \tau_2 P_{mat}^2 + \mu_m\right] \tag{C6}$$

The expected price of a one year earlier vehicle in year t (i.e. $\widehat{P}_{mat}$) can be obtained by first estimating a logit regression of the form given in equation (C7).

$$\ln\left[\frac{\overline{P}_{mat}}{P_{mat}}\right] = \Delta_0 + \sum_{m=1}^{M-1} \Delta_k (MK)_m + \sum_{a=1}^{A-1} \Delta_a D_a \tag{C7}$$

where $(MK)_m$ is a m^{th} make-specific dummy variable; and D_a is a d^{th} vintage-specific dummy variable. The estimated value of $\widehat{\widehat{P}}_{mat}$ can then be derived from equation (C7) given the value of $\widehat{P}_{mat}$ from equation (C1), using the relationship in equation (C8).

$$\widehat{\widehat{P}}_{mat} = \widehat{P}_{mat} \exp\left(\Delta_0 + \sum_{m=1}^{M-1} \Delta_k (MK)_m + \sum_{a=1}^{A-1} \Delta_a D_a\right) \tag{C8}$$

Appendix D. Defining Urban Areas in Australia

The current study is concerned with the demand for passenger transport in urban areas of Australia. Although we will collect data for a subset of all urban areas, albeit a large percentage of the urban population, the estimated models have the capability of being applied to all of urban Australia. For the purposes of this exercise, the Australian Standard Geographical Classification system consists of the following hierarchy: States, Statistical Divisions, Statistical Subdivisions and Statistical Local Areas.

For each capital city in Australia, the city is defined by 1991 ABS Statistical Divisions. The population and subdivision composition of each capital city statistical division appears in the following tables. There are satellite commuting zones surrounding our larger cities, and the possibility of including these zones in the "applications" phase of the project has been recognised. The extra zones which may be included are the shaded sections of the tables.

Table D1: Urban New South Wales

Statistical Division	Statistical Subdivision	1991 Census Population
Sydney		**3,538,970**
	Inner Sydney	262,261
	Eastern Suburbs	224,348
	St George-Sutherland	378,791
	Canterbury-Bankstown	283,170
	Fairfield-Liverpool	273,322
	Outer South Western Sydney (Camden, Campbelltown, Wollondilly)	190,640
	Inner Western Sydney	148,070
	Central Western Sydney	260,439
	Outer Western Sydney (Blue Mtns, Hawkesbury, Penrith)	270,461
	Blacktown-Baulkham Hills	325,804
	Lower North Sydney	258,463
	Hornsby-Ku-ring-gai	226,887
	Manly-Warringah	206,907
	Gosford-Wyong	229,407
Hunter		**513,550**
	Newcastle	427,703
	Hunter SD Balance	85,847
Illawarra		**337,524**
In survey	Wollongong	236,010
	Illawarra SD Balance	101,514

Table D2: Urban Victoria

Statistical Division		Statistical Subdivision	1991 Census Population
Melbourne			**3,022,439**
		Central Melbourne	227,420
		Western Inner Melbourne	121,665
		Western Outer Melbourne	234,588
		Western Fringe Melbourne	106,966
		Northern Inner Melbourne	90,511
		Northern Middle Melbourne	184,011
		Northern Fringe Melbourne	142,297
		Northern Outer Melbourne	199,088
		Eastern Inner Melbourne	141,096
		Eastern Middle Melbourne	266,302
		Eastern Outer Melbourne	299,565
		Eastern Fringe Melbourne	141,275
		Southern Inner Melbourne	171,665
		Southern Outer Melbourne	175,637
		South Eastern Inner Melbourne	146,753
		South Eastern Outer Melbourne	167,584
		Mornington Peninsula Inner	110,808
		Mornington Peninsula Outer	95,216
Barwon			**218,006**
	In survey	Geelong	145,325
		East Barwon	39,420
		West Barwon	33,261

Table D3: *Urban Queensland*

Statistical Division		Statistical Subdivision	1991 Census Population
Brisbane			**1,334,746**
		Brisbane City	751,225
		Albert Shire Part A	32,896
		Beaudesert Shire Part A	16,561
		Caboolture Shire Part A	66,487
		Ipswich-Moreton Shire Part A	108,035
		Logan City	143,107
		Pine Rivers Shire	87,926
		Redcliffe City	47,814
		Redland Shire	80,695
Moreton			**514,191**
	In survey	Gold Coast City	157,859
		Albert Shire Part B (Gold Coast hinterland to Nerang)	110,816
	In survey	Sunshine Coast	126,142
		Moreton SD Balance	119,374

Table D4: *Urban Western Australia*

Statistical Division	Statistical Subdivision	1991 Census Population
Perth		**1,143,256**
	Central Metropolitan	140,957
	East Metropolitan	185,443
	North Metropolitan	340,592
	South West Metropolitan	224,678
	South East Metropolitan	251,595

Table D5: Urban South Australia

Statistical Division	Statistical Subdivision	1991 Census Population
Adelaide		**1,023,617**
	Northern	311,180
	Western	306,137
	Eastern	212,031
	Southern	294,269
Outer Adelaide		**89,257**
	Barossa	36,974
	Kangaroo Island	3,903
	Onkaparinga	24,949
	Fleurieu	23,433

Table D6: Urban Australian Capital Territory

Statistical Division	Statistical Subdivision	1991 Census Population
Canberra		**278,894**
	Central Canberra	61,000
	Belconnen	85,508
	Woden Valley	32,617
	Weston Creek	25,718
	Tuggeranong	71,602
	Outer Canberra	2,449

Note: Queenbeyan will be included as the NSW sector of Canberra.

Table D7: Urban Tasmania (not in study)

Statistical Division	Statistical Subdivision	1991 Census Population
Greater Hobart		**181,838**
	Greater Hobart	181,838
Northern	Greater Launceston	93,347
Mersey-Lyell	Burnie-Devenport	75,617

Table D8: Urban Northern Territory (not in study)

Statistical Division	Statistical Subdivision	1991 Census Population
Darwin		**78,139**
	Darwin City	69,809
	Palmerston-East Arm	8,330

Appendix E. Ordered Choice Models

Ordered choices can be modelled by either ordered logit or ordered probit. Formally, let R denote an unobserved continuous rating variable ($-\infty < R < +\infty$), and ω_0, $\omega_1, \ldots, \omega_{J-1}$, ω_J denote the cut-off or threshold points in the distribution of R, where $\omega_0 = -\infty$ and $\omega_J = +\infty$. Define R^* to be an ordinal (observed rating) variable such that $R^* = j$ if, and only if, $\omega_{J-1} \leq R \leq \omega_J$ ($j = 1,2,\ldots,5$). Since R is not observed (but R^* is observed), its mean and variance are unknown. Statistical assumptions must be introduced such that R has a mean of zero and a variance of one. To operationalise the model, we define a relationship between R and R^*. Consider the likelihood of obtaining a particular rating value of R and the probability that R^* takes on a specific rating value. If R follows a probability distribution such as normal with density function f(R) and a cumulative density function F(R), then the probability that $R^* = j$ is the area under the density curve between ω_{j-1} and ω_j. Formally this is given by (Winship and Mare 1984):

$$P(R^*=j) = \int_{\omega_{j-1}}^{\omega_j} f(R)\, dR = F(\omega_j) - F(\omega_{j-1}),$$

where $F(\omega_j) = 1$ and $F(\omega_{j-1}) = 0$

For a sample of individuals for whom R^* is observed, we can estimate the thresholds ω_j as $\omega_j = F^{-1}(p_j)$, where p_j is the proportion of observations for which $R^* < j$ and F^{-1} is the inverse of the cumulative density function of R. Given empirical estimates of ω_j, we can obtain estimates of the mean of R for observations within each interval of the rating scale. If R is a standard normal, its mean for the sample for which $R^* = j$ is:

$$R_{\omega_j,\omega_{j-1}} = \frac{\phi(\omega_{j-1}) - \phi(\omega_j)}{\Phi(\omega_j) - \Phi(\omega_{j-1})}$$

where ϕ is the standardised normal probability density function and Φ is the cumulative standardised normal distribution function. Explanatory variables obtained from both the experimental designs and contextual data can be readily incorporated into the ordered response model in the usual manner that they are incorporated into a regression equation. If we assume that the randomly distributed error term is uncorrelated with the observed explanatory variables and its probability distribution is normal, then the ordered response model is referred to as ordered probit.

The implication of this distributional assumption is that the probability that R^* takes on successively higher values increases or decreases slowly at small values of the explanatory variables, more rapidly for intermediate values, and more slowly again at large values. A linear model assumes the probability that R^* takes successively higher values increases or decreases a constant amount over the entire range of the explanatory variables. The advantages of ordered probit over a linear (probability regression) model are greatest when R^* is highly skewed.

The LIMDEP package (Econometric Software 1992) automates ordered probit and ordered logit, making it easy to obtain parameter estimates for the design and socioeconomic variables, as well as the threshold parameters. *The latter set of parameters indicate the extent to which the categories of the rating scale are equally spaced in the probit scale.* All parameters are obtained by iterative maximum likelihood estimation, using the Davidson-Fletcher Powell optimisation method with the first derivatives used to define the variance matrix. Starting values are obtained by ordinary least squares regression on a binary dependent variable. Sample cell frequencies on the observed ratings are used to initially divide up the real line in order to define the starting threshold values on a normalised scale. The lowest threshold is normalised to zero.

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